arine Physical Laboratory

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Acoustic Modem: March 16, 1989 Trip Report

A. Dotan, W. S. Hodgkiss, G. L. Edmonds, and J. C. Nickles

MPL Technical Memorandum 423
November 1990

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University of California, San Diego
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) MPL Technical Memorandum 423 [MPL-U-91/90]	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION University of California, San Diego 6b. OFFICE SYMBOL (If applicable) MPL	7a. NAME OF MONITORING ORGANIZATION Naval Research Laboratory
6c. ADDRESS (City, State, and ZIP Code) Marine Physical Laboratory Scripps Institution of Oceanography San Diego, California 92152	7b. ADDRESS (City, State, and ZIP Code) 4555 Overlook Avenue, S.W. Washington, D.C. 20375-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Research Laboratory 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-88-K-2040
8c. ADDRESS (City, State, and ZIP Code) 4555 Overlook Avenue, S.W. Washington, D.C. 20375-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Acoustic Modem: March 16, 1989 Trip Report

12. PERSONAL AUTHOR(S)

A. Dotan, W. S. Hodgkiss, G.L. Edmonds, and J. C. Nickles

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
tech memo	FROM ____ TO ____	November 1990	89 pages

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Swallow float, sonobuoy, acoustic communication link.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

An experiment was conducted on 16 March 1989 as part of a project investigating the design of an acoustic communication link between a Swallow float and a sonobuoy. The objective of the experiment was to measure the transmission characteristics of the acoustic channel at high frequency (10 to 20 kHz), including the nature of fading and multipath.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL W.S. Hodgkiss	22b. TELEPHONE (Include Area Code) (619) 534-1798 22c. OFFICE SYMBOL MPL

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

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ABSTRACT

An experiment was conducted on 16 March 1989 as part of a project investigating the design of an acoustic communication link between a Swallow float and a sonobuoy. The objective of the experiment was to measure the transmission characteristics of the acoustic channel at high frequency (10 to 20 kHz), including the nature of fading and multipath.

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I Introduction

An experiment was conducted on 16 March 1989 as part of a project investigating the design of an acoustic communication link between a Swallow float and a sonobuoy. The experiment was located at 32°40'N and 117°35.6'W. During the experiment, the sea state was between zero and one and the wind speed was between 5 and 12 knots.

The objective of the experiment was to measure the transmission characteristics of the acoustic channel at high frequency (10 to 20 kHz), including the nature of fading and multipath.

II Experiment Concept.

The experiment plan was to transmit a set of waveforms from a transducer deployed deep in the ocean from a ship (R/V SPROUL) and receive the transmitted signal with four sonobuoys located 1 km apart and transmitting the received signal via a RF link back to the ship (see Figures 2.1 and 2.2). The transmitted and the received signals (from the sonobuoys) were recorded simultanously. In addition, a monitor hydrophone was deployed close to the projector and provided a replica of the waveforms which were transmitted through the water.

Figure 2.1 and Figure 2.2 show a schematic diagram of the experiment set up.

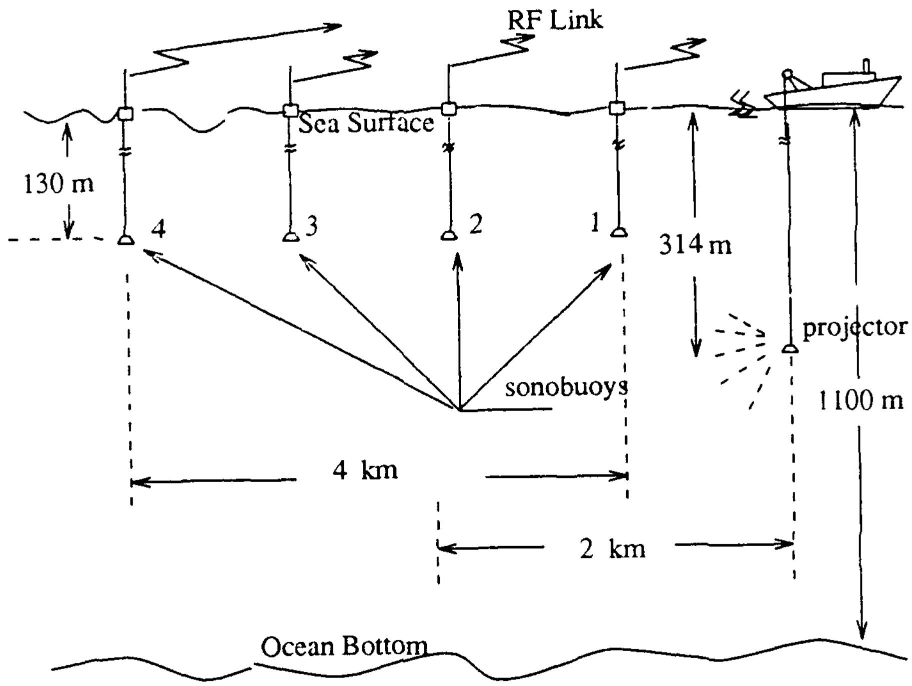


Figure 2.1 Experiment Setup.

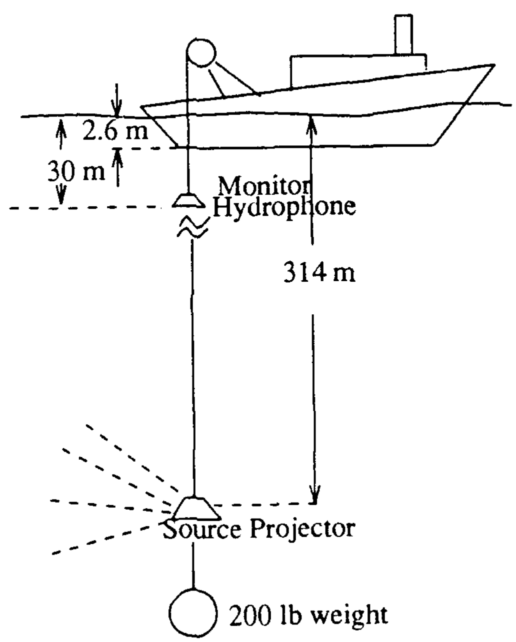


Figure 2.2. Projector and Monitor Hydrophone Location.

As a projector, we used a Sparton model 6130 free flooded ring transducer which transmitted a signal of source level of 182 DB/1μPa @ 1m. As receivers, we used the AN/SSQ-57 sonobuoys with frequency response shown in Figure 2.3.

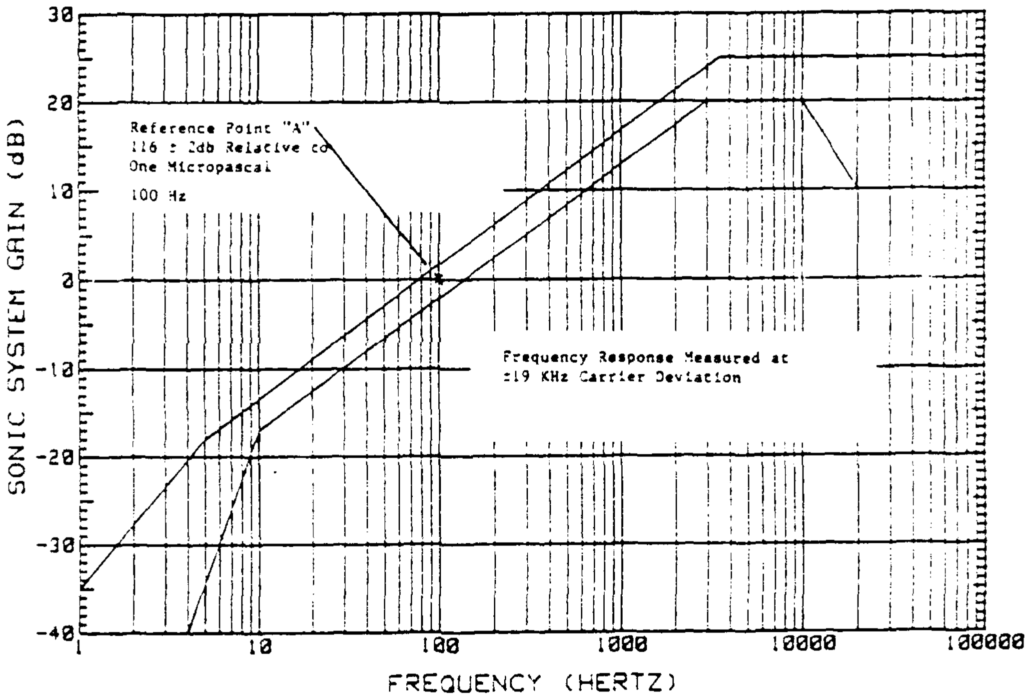


Figure 2.3. The frequency response of the AN/SSQ-57 sonobuoy.

II.1 Signal set

Three sets of waveforms were transmitted:

(1) Discrete frequency pulses. A sequence of 16 pulses centered at 9 to 16.5 kHz, with 500 Hz separation was transmitted. The time interval between the pulses was 1 sec. Two sets of pulses were transmitted: (a) 2 msec (defined as set No. 1.1) and (b) 0.25 msec length (defined as set No. 1.2).

(2) Chirp waveform Two sets of chirp waveforms were transmitted: (a) 2 msec up chirp pulse centered at 15 kHz and 10 kHz bandwidth was transmitted every second (defined as set No. 2.1) and (b) A train of 2 msec chirp pulses centered at 15 KHz and with 10 Khz bandwidth (defined as set No. 2.2)

(3) Two tones selected randomly. Two tones at 12 and 13 kHz were selected by a pseudo random sequence (PRN). The switching period was varied from 1 to 100 msec. Table 1 summarizes the switching period and the corresponding PRN sequences.

Switching Period	PRN Seq. Length	PRN Seq. length
msec	bits	sec
1	8191	8.2
2	4095	8.2
5	2047	10.2
10	1023	10.2
20	511	10.2
50	255	12.8
100	127	12.7

Table 1. Switching period and PRN sequence length.

II.2 Measuring setup

Figure 2.4 gives a schematic block diagram of the measuring setup used in the experiment.

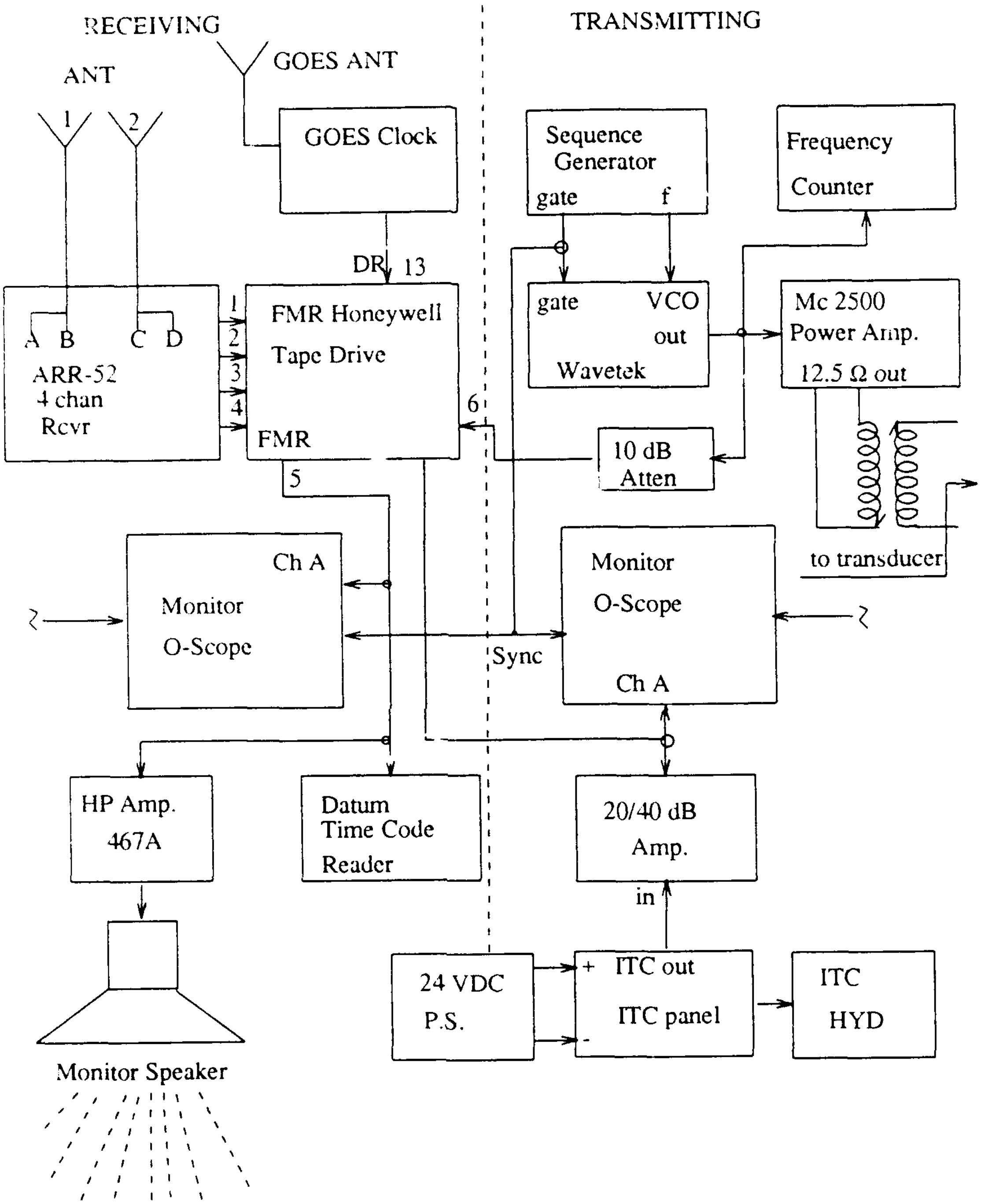


Figure 2.4. Measuring setup.

The right hand side of the block diagram describes the wave form generator, power amplifier, and transmitted signal monitoring. The left hand side describes the receiving part including the 4 channel FM receiver, GOES clock, Honeywell 101 tape recorder, and received signal monitoring. Table 2 describes the signals that were recorded on each of the Honeywell tape recorder channels

Signal From	Recorded on Channel #
sonobuoy # 1	1
sonobouy # 2	2
sonobouy # 3	3
sonobouy # 4	4
monitor hydrophone	5
synthesized waveform	6

Table 2. The content of each channel of the tape recorder.

The receiving system was calibrated such that for channels 1-4, an input signal level to the sonobuoy of 106 dB re1μPa@440Hz corresponds to 0.51 Vrms at the tape recorder reproducing output. For channel 5, input signal level to the hydrophone of 106 dB re1μPa@440Hz corresponds to 1.414 Vrms at the tape recorder reproducing output. For the calibration at other frequencies, see SSQ-57 frequency response (Figure 2.3)

Figure 2.5 shows the setup that was used for digitizing the analog recorded data and storing it on Exabyte tapes.

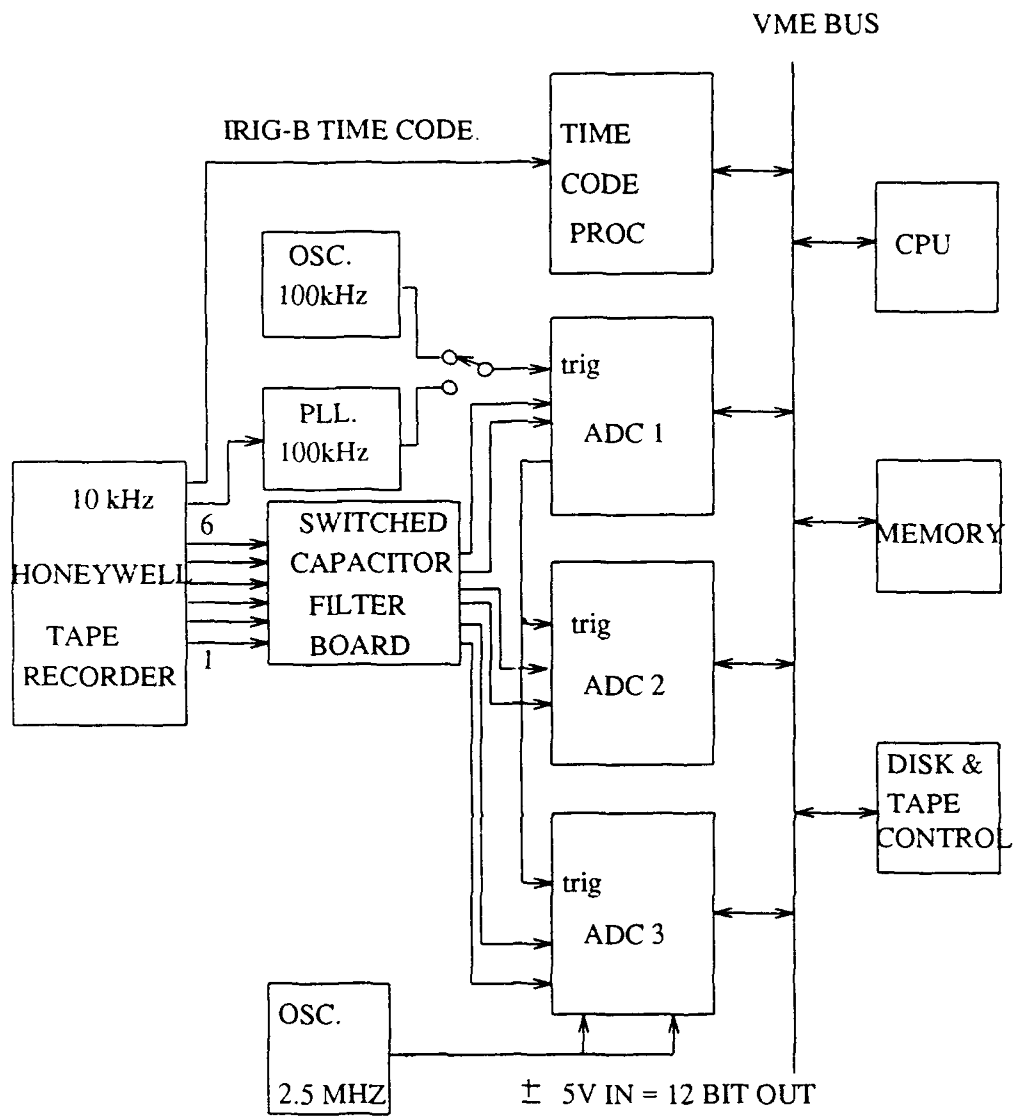


Figure 2.5. Digitizing setup.

The digitizer was calibrated such that 1 volt at the output of the tape recorder corresponds to 1 volts at the input to the anlog to digital converter (ADC). Figure 2.6 gives the frequency response of the antialaising filter that was used.

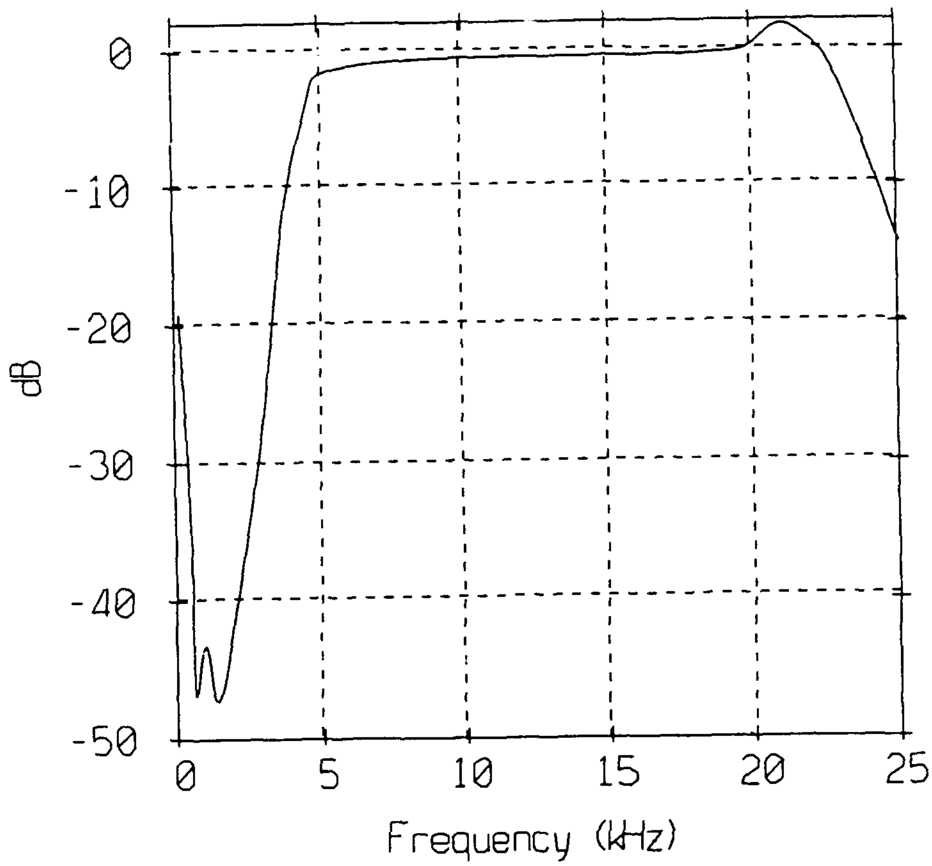


Figure 2.6. Antialaising filter frequency response.

II.3 XBT measurements

Expendable bathythermograph (XBT) measurment was made from the R/V SPROUL at the begining of the experiment. The Sippican model T-4 XBT was used. This temperature measurement along with historical salinity data archived by the National Oceanographic Data Center[1] was used with an equation relating temperature, salinity and depth to sound speed[2] Figure 2.7 shows the sound speed profile as calculated from the XBT data.

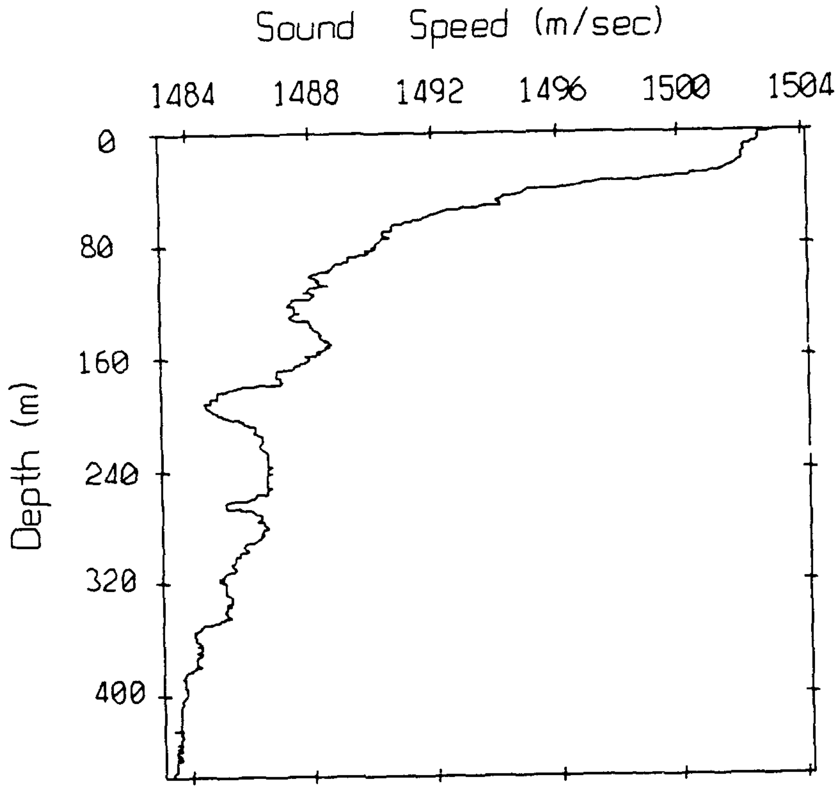


Figure 2.7. XBT sound speed profile.

Figure 2.8 compares the sound speed profile calculated from the XBT data with a sound profile based on historical data.

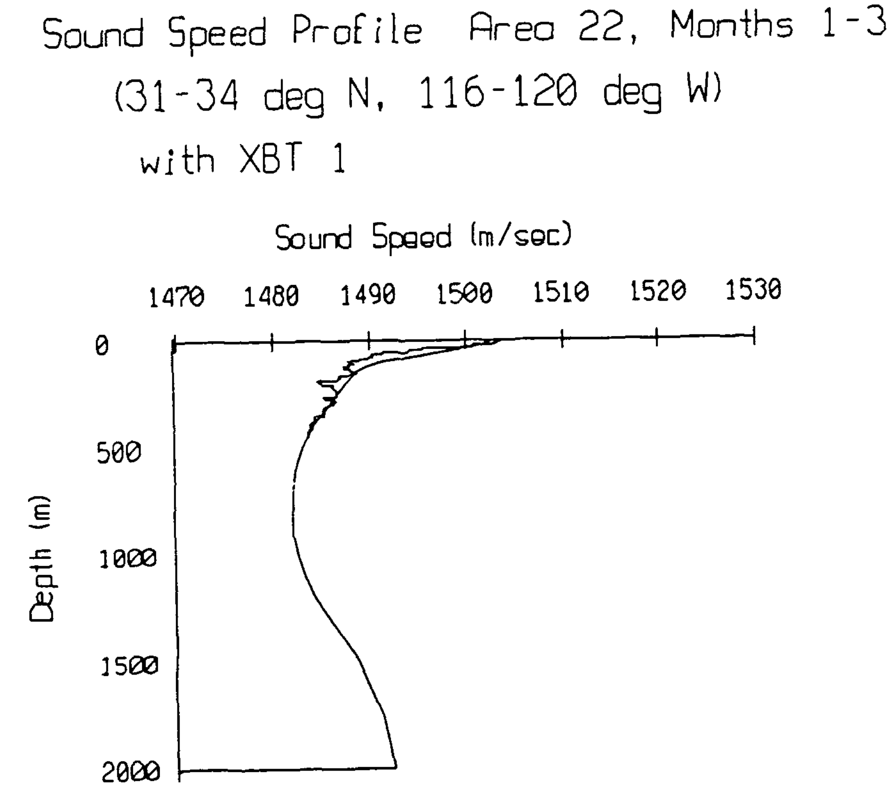


Figure 2.8. XBT sound speed profile compared with historical data.

II.4 Log summary

In this section, two lists are enclosed. The first is the experiment log as was written in the log book during the experiment and the second is the contents of each of the digital tapes.

II.4.1 Experiment log

16 March, 1989 Acoustic Modem Experiment No. 1, (R/G SPROUL)

10:40 Arriving on station.

10:44 Taking XBT at $32^0 40.00' N$ $117^0 36.15' W$.

10:59 Deploy buoy 18 at $32^0 39.88' N$ $117^0 36.54' W$.

11:13 Buoy 18 appears to be buoy 2 on receiver (channel 1).

13:11 Buoy No 2 deployed at $32^0 40.7' N$ $117^0 36.82' W$.

13:25 Buoy No 4 deployed at $32^0 40.92' N$ $117^0 37.23' W$.

13:39 Buoy No 6 deployed at $32^0 41.11' N$ $117^0 37.62' W$.

13:49 Buoy No 15 deployed at $32^0 41.14' N$ $117^0 37.90' W$.

14:07 Deploy the source at $32^0 41.86' N$ $117^0 39.00' W$.

14:27 $32^0 41.86' N$ $117^0 39.00' W$. The source is at depth of 314 m,

the monitor hydrophone at 33 m

14:46 Start recording at $32^0 41.46' N$ $117^0 38.98' W$.

Adding 20 dB gain in Clevite (142 dB sensitivity instead of 162 dB)

14:47 Freighter 3 miles to port.

15:12 Adjusting channels 1-4 on Honeywell 101 for 0.5 V r.m.s instead of 1.414.

Channels 5-6 adjusted for 1.414 V.

15:14:12 Start transmitting 2 ms pings at $32^0 41.41' N$ $117^0 38.96' W$.

(ft counter on the tape recorder = 0).

15:27:23 Begin 0.25 msec pings (ft counter = 1995).

15:31:25 Took 20 dB out of Clevite (ft counter = 2680).

15:33:10 Put 20 dB in Clevite (ft counter = 2900).

15:34:29 Begin transmitting PRN (ft counter = 3028).

15:36:35 Switch transmit power level down 10 dB (ft counter = 3375).

15:43:25 Stop (ft counter = 4374).

Reduce transmitting power 10 dB.

16:04:42 Second tape is installed.

16:06:03 Begin 2 ms pings $32^0 41.12'N$ $117^0 39.08'W$. (ft counter = 0).

100 V p-p at the secondary of the drive transformer

16:14:03 Begin transmitting 0.25 msec pulses (ft counter = 1250).

16:24:03 Begin transmitting PRN (ft counter = 2703).

16:34:15 Stop (ft counter = 4236S).

16:41 Third tape is installed.

Increase power to maximum, Clevite 0 dB gain.

600 V p-p at the secondary of the drive transformer.

16:50:32 Begin transmitting 2 ms pulses. (ft counter = 0).

16:55:15 20 dB gain is added to the Clevite.

16:56:30 Begin transmitting 0.25 msec pulses (ft counter = 895).

17:01:59 Begin transmitting PRN (ft counter = 1650).

17:06:30 Stop.

Set up FM Chirp 10-20 kHz 2 msec duration, with repetition rate of 1 sec.

17:16:07 Begin transmitting chirp pulses (ft counter = 2399).

17:21 $32^0 41.15' N$ $117^0 39.43' W$.

10 dB down in transmitting power.(ft counter = 3145).

17:26 Fnd.

17:29:24 Begin transmitting continuous chirps (ft counter = 3909).

17:33 End (ft counter = 3909).

18:18 Head home.

II.4.2 Contents of digital tapes

The digitized data has been archieved in SIO data file format. Each tape contains 14 files, 2 min long each. The enclosed list gives the starting time of each file.

::::::::::::::::::::

Digital tape number 1

::::::::::::::::::::

075 15:14:12.000000 Begin 2 ms. pulses

075 15:16:12.000000 2 ms. pulses

075 15:18:12.000000 2 ms. pulses

075 15:20:12.000000 2 ms. pulses

075 15:22:12.000000 2 ms. pulses

075 15:24:12.000000 2 ms. pulses

075 15:27:23.000000 Begin .25 ms. pulses

075 15:29:23.000000 .25 ms. pulses

075 15:31:23.000000 .25 ms. pulses

075 15:34:29.000000 Begin PRN

075 15:36:29.000000 PRN

075 15:38:29.000000 PRN

075 15:40:29.000000 PRN

075 15:42:29.000000 PRN

::::::::::::::::::::::

Digital tape number 2

::::::::::::::::::::::

075 16:06:03.000000 Begin 2 ms. pulses

075 16:08:03.000000 2 ms. pulses

075 16:10:03.000000 2 ms. pulses

075 16:12:03.000000 2 ms. pulses

075 16:14:03.000000 Begin .25 ms. pulses

075 16:16:03.000000 .25 ms. pulses

075 16:18:03.000000 .25 ms. pulses

075 16:20:03.000000 .25 ms. pulses

075 16:22:03.000000 .25 ms. pulses

075 16:24:03.000000 Begin PRN

075 16:26:03.000000 PRN

075 16:28:23.000000 PRN

075 16:30:23.000000 PRN

075 16:32:23.000000 PRN

::::::::::::::::::::::

Digital tape number 3

::::::::::::::::::::::

075 16:50:32.100000 Begin 2 ms. pulses

075 16:52:32.100000 2 ms. pulses

075 16:54:32.100000 2 ms. pulses

075 16:56:32.100000 Begin .25 ms. pulses

075 16:58:32.100000 .25 ms. pulses

075 17:01:59.100000 Begin PRN

075 17:03:59.1C)000 PRN

075 17:16:07.100000 Begin FM chirp

075 17:18:07.100000 FM chirp

075 17:20:07.100000 FM chirp

075 17:22:07.100000 FM chirp

075 17:24:07.100000 FM chirp

075 17:29:34.100000 Begin continuous chirp

075 17:31:34.100000 Continuous chirp

III Data analysis

III.1 Signal presentation

Figures 3.1 and 3.2 show the power specra of a sequence of 28 2msec pulses (set No. 1.1). The spectra of the synthesized waveforms are shown in Figure 3.1 and the spectra of the received pulses as were received in hydrophone No 4 is shown in Figure 3.2. The received direct signal and the first multipath signal of each of the pulses as received in hydrophone No 4 is shown in Figure 3.3.

Figure 3.4 shows one of the synthesized 2 msec chirp waveform (set No 2.1). Figures 3.5 and 3.6 show one of the received chirp pulses as received by sonobuoys No 2 and No 4. These two Figures show time record of 1 second. The received direct signal, and the first three multipath signals are clearly seen in the Figures. Comparing Figures 3.5 and 3.6 shows a big different in the multipath pattern which leads to the conclusion that the channel character depends also on the location of the transmitter and the receiver, and the distance between them.

The chirp transmitted pulses were received by all four sonobuoys. Figures 3.7-3.34 and 3.35-3.62 show the recieved direct path signal and the first multipath signal of a group of 28 2 msec chirp signals. Figures 3.7-3.34 correspond to sonobuoy No 2 and Figures 3.35-3.62 correspond to sonobuoy No 4.

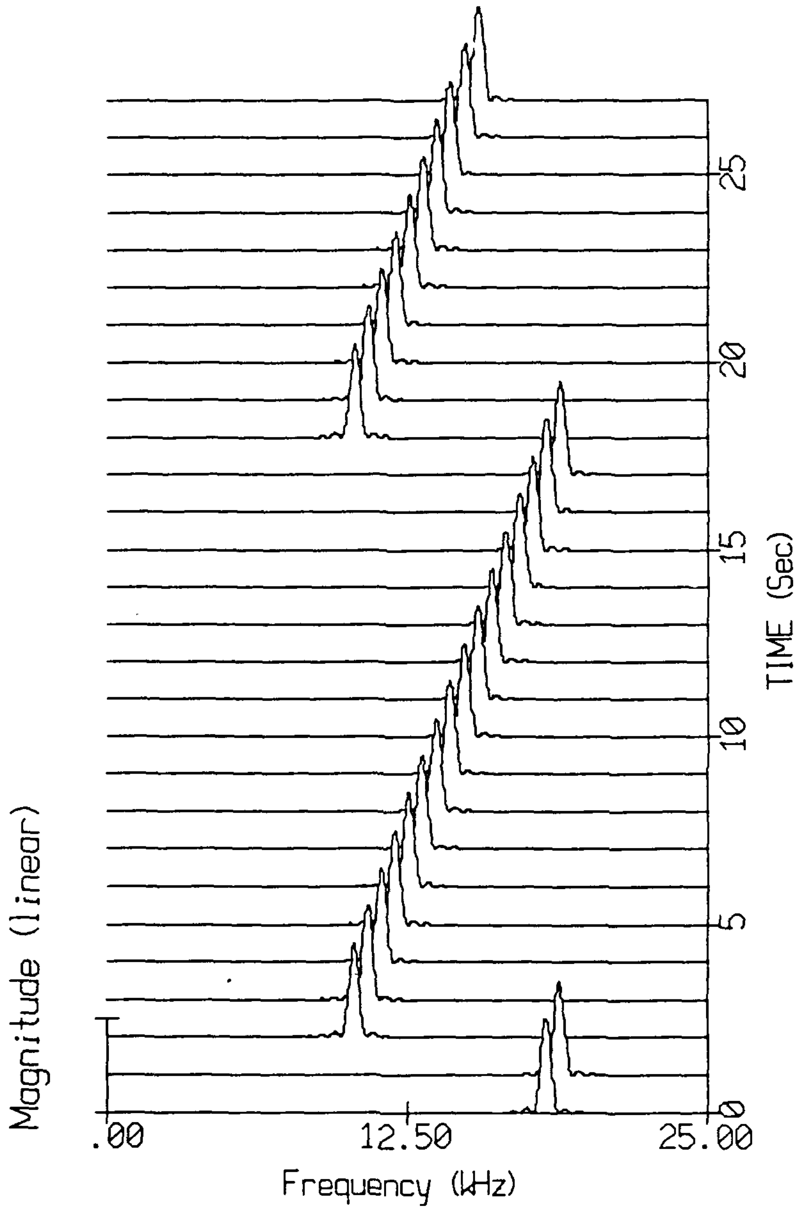


Figure 3.1. The spectra of the synthesized 28 2 msec tone pulses .

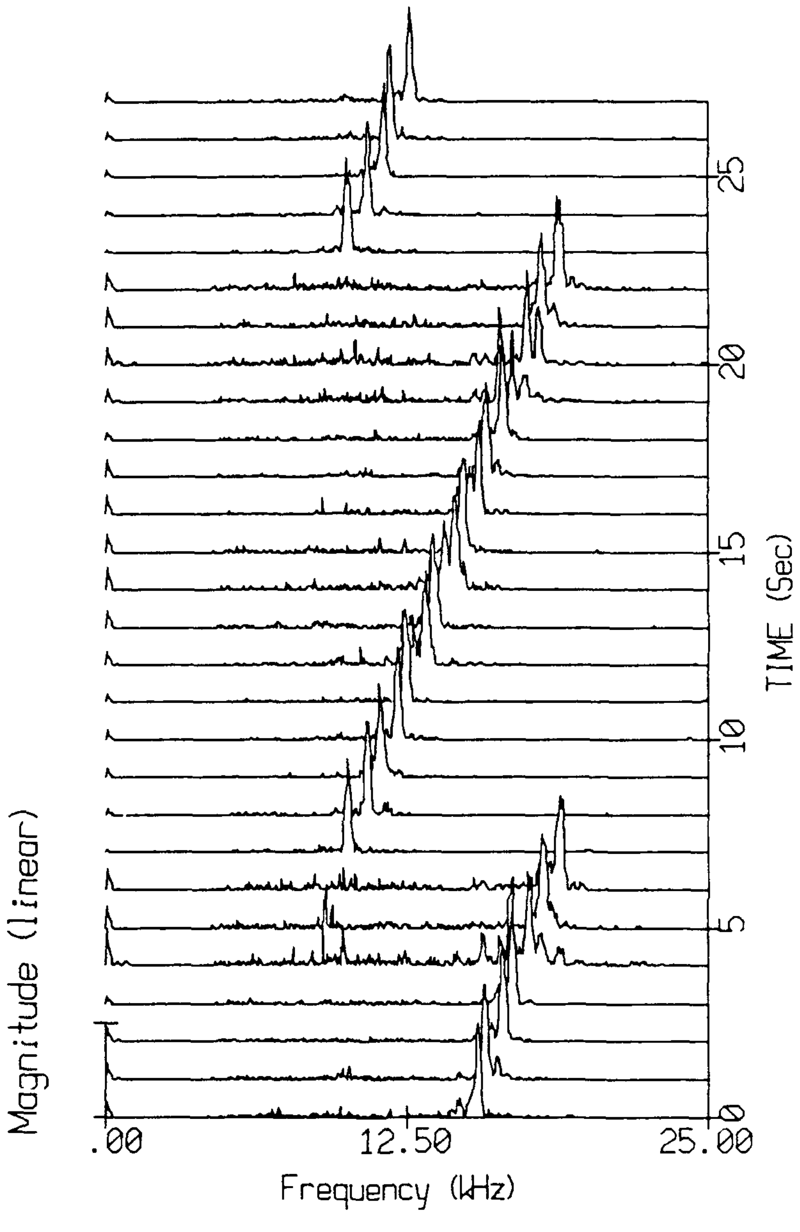


Figure 3.2. The spectra of the 28 2 msec tone pulses recieved at sonobuoy No 4.

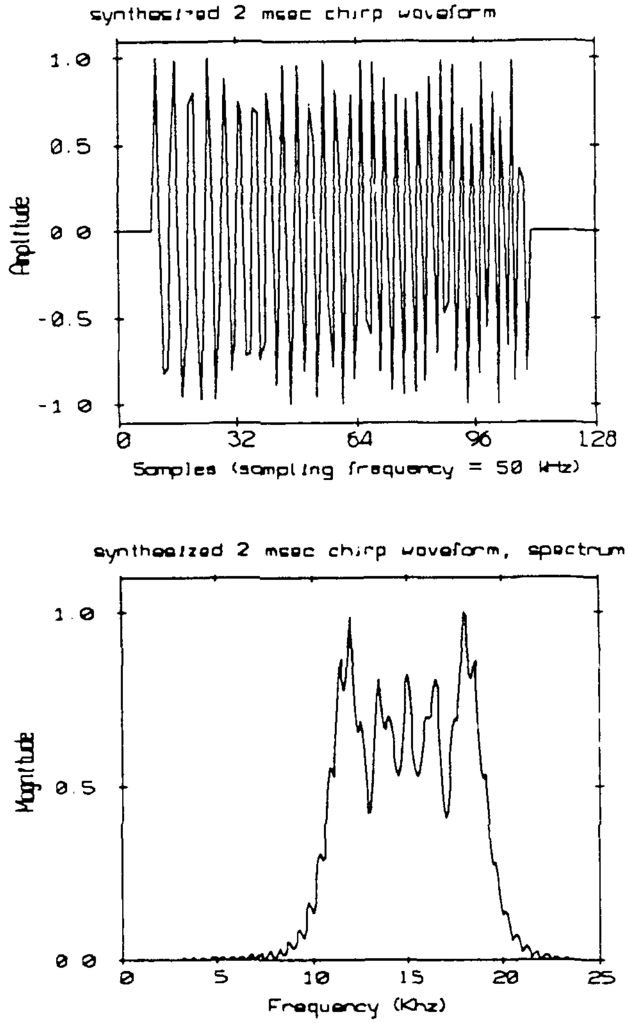


Figure 3.3. The synthesized 2 msec chirp waveform.

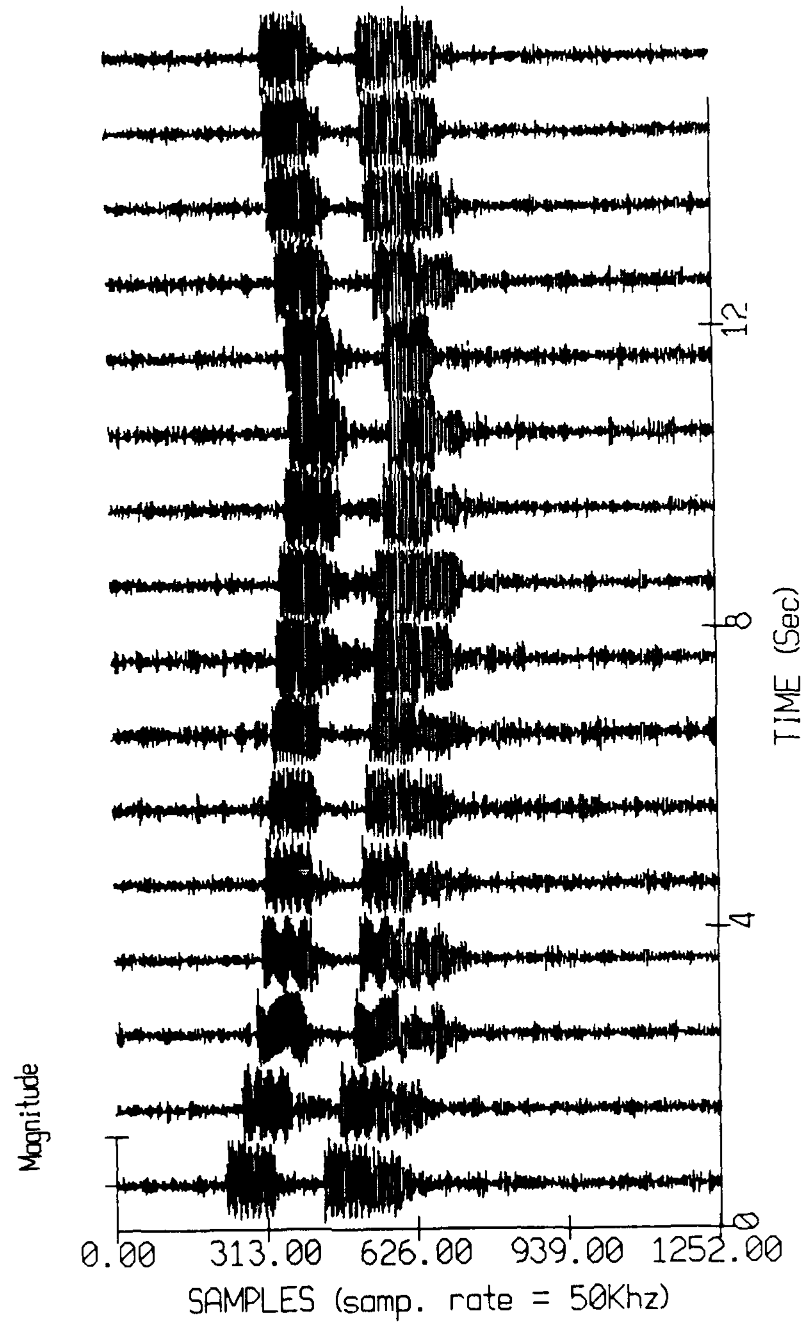


Figure 3.4. The direct signal and the first multipath of the 28 2msec tone pulses as received by sonobuoy No 4.

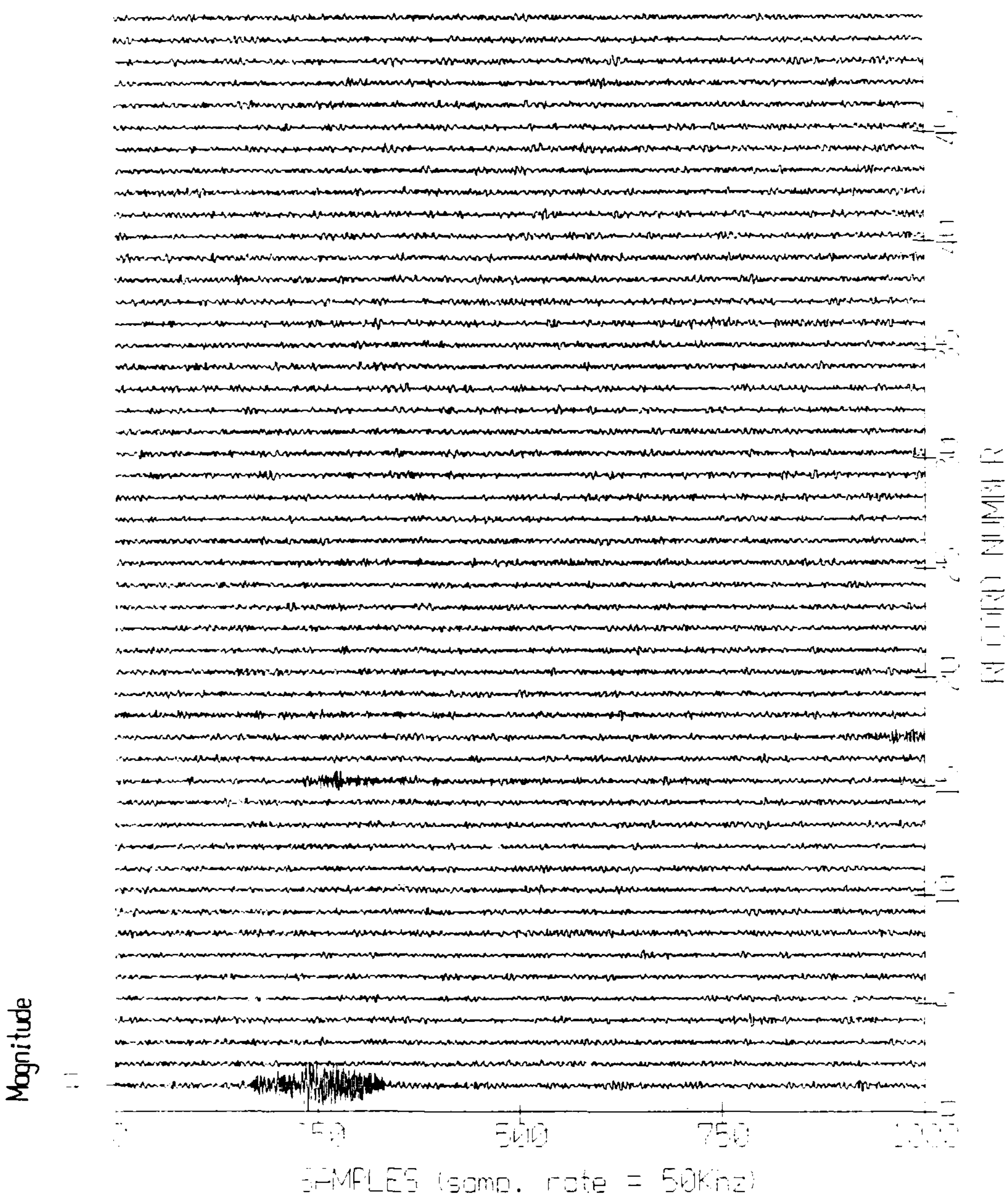


Figure 3.5. The 2 msec chirp waveform as received by sonobuoy No 2.

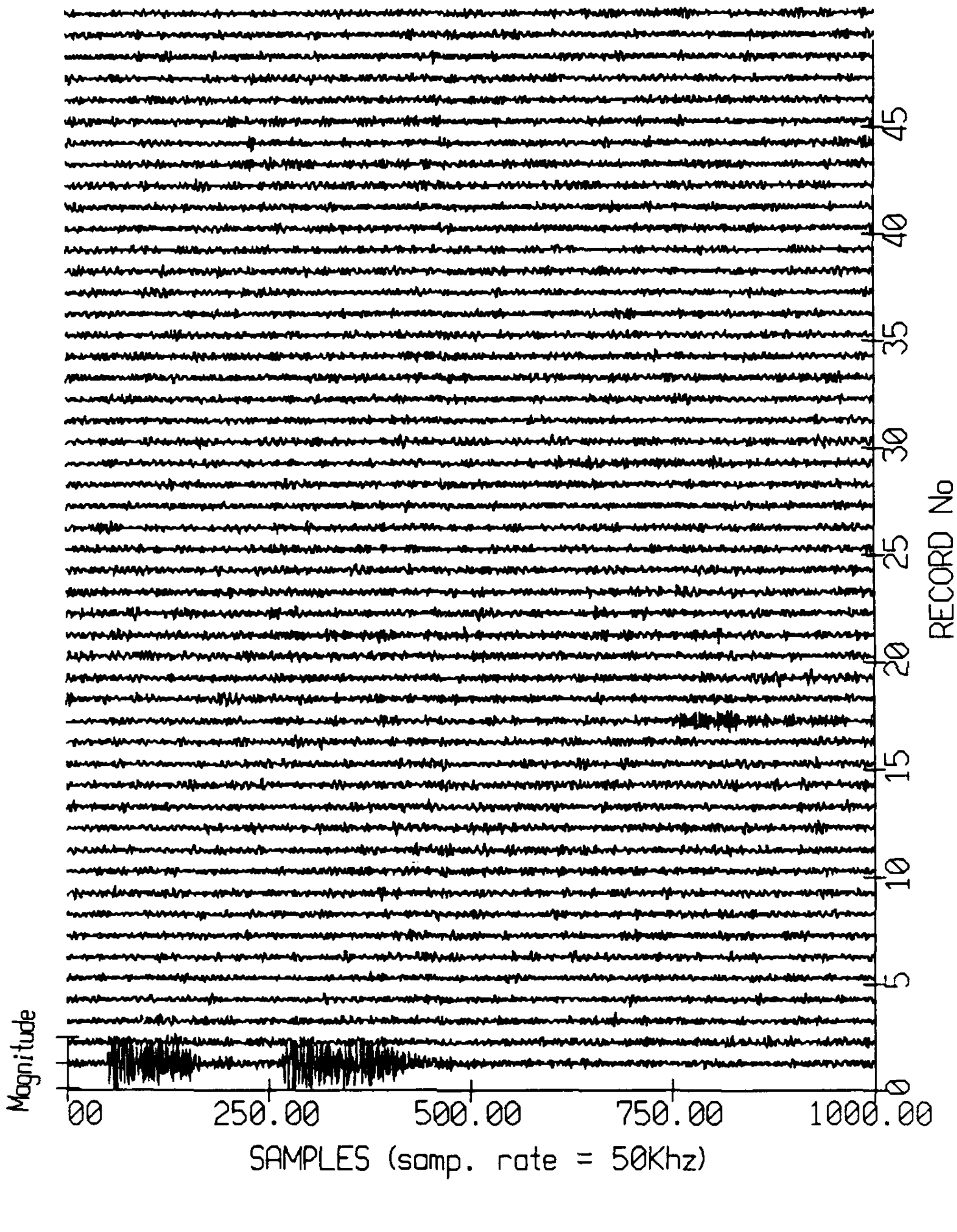


Figure 3.6. The 2 msec chirp waveform as received by sonobuoy No 4.

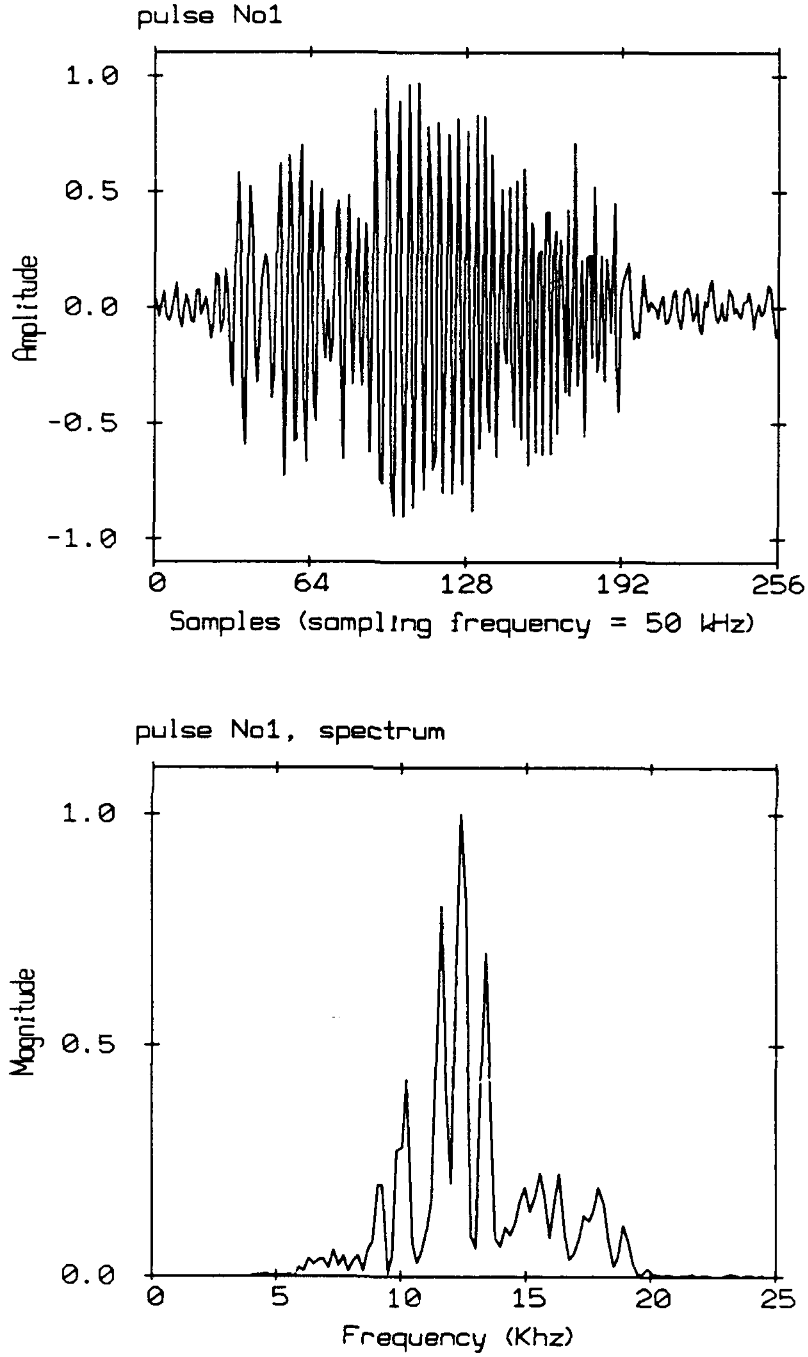
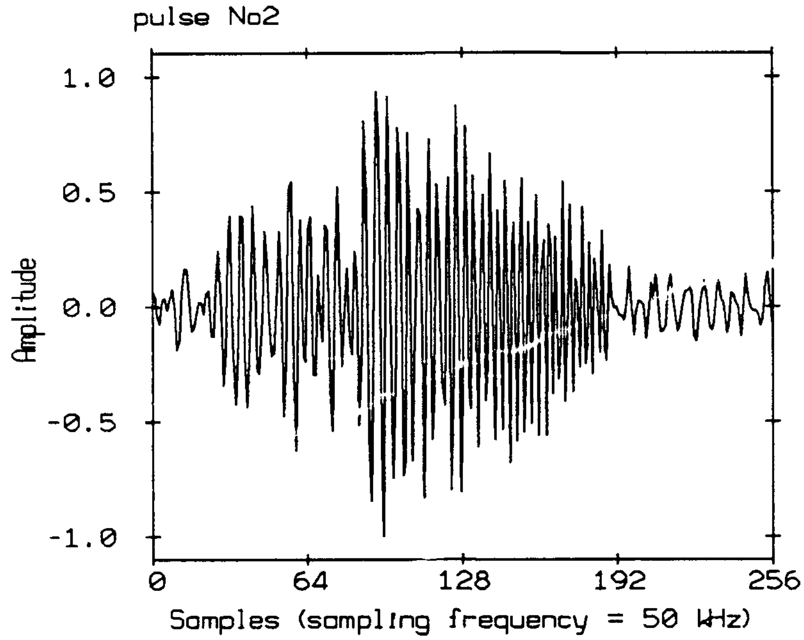
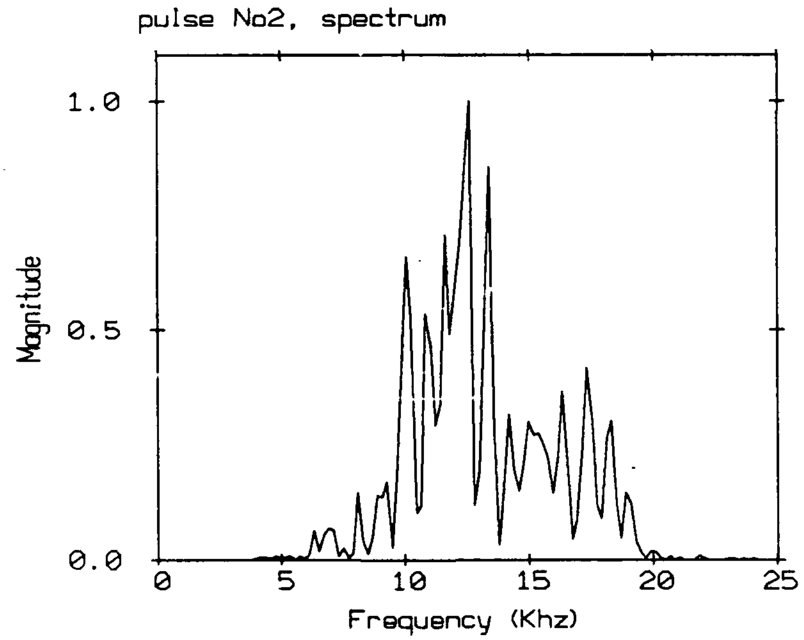
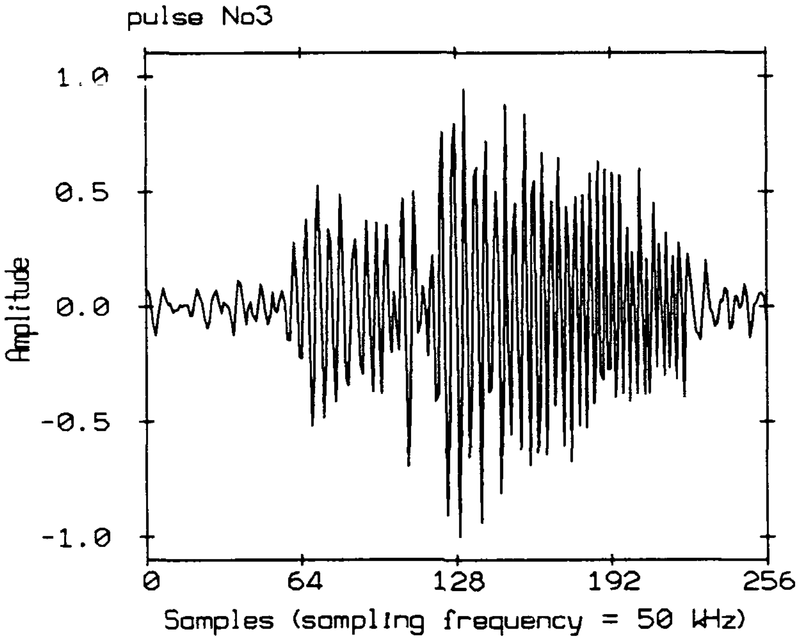


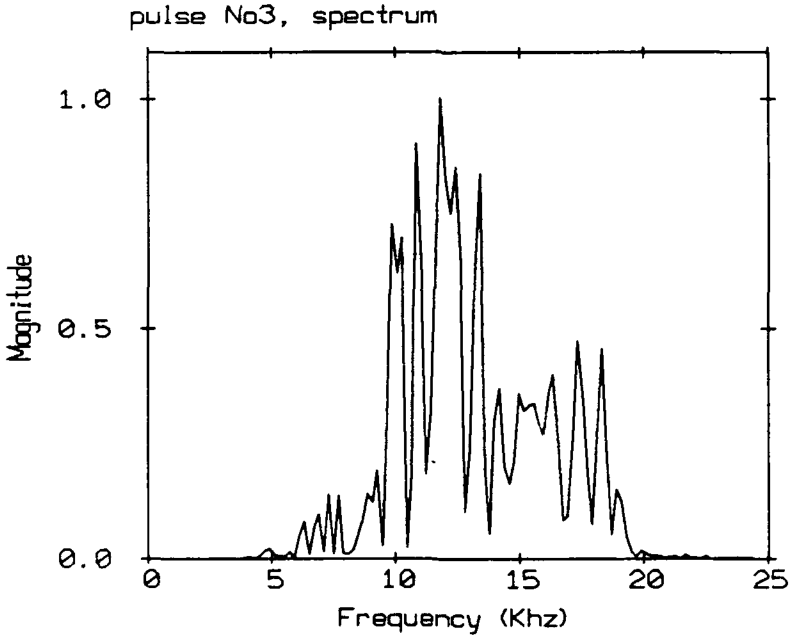
Figure 3.7-3.34. The direct signal and the first multipath of the 28 2msec chirps as received by sonobuoy No 2.



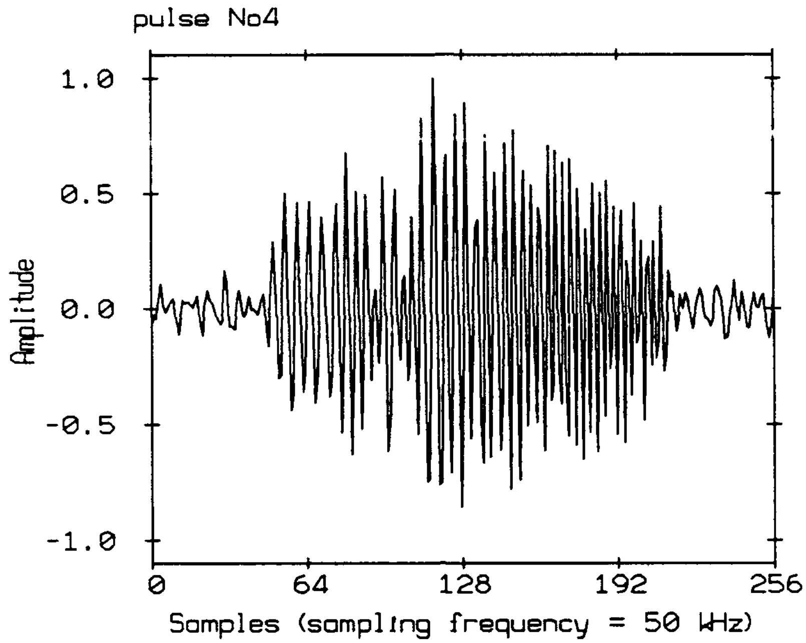


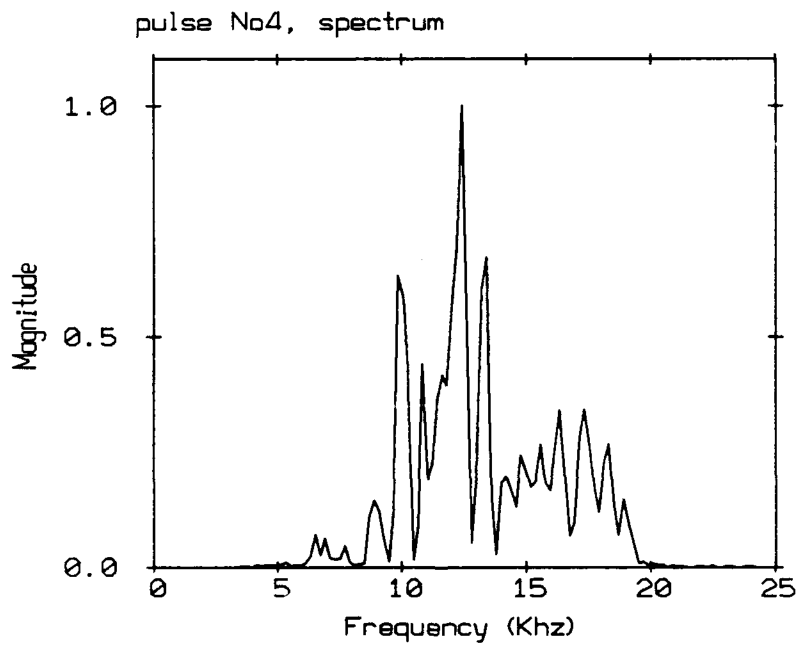
171607.1.ch2 , pulse No2





1?1607.1.ch2 , pulse No3





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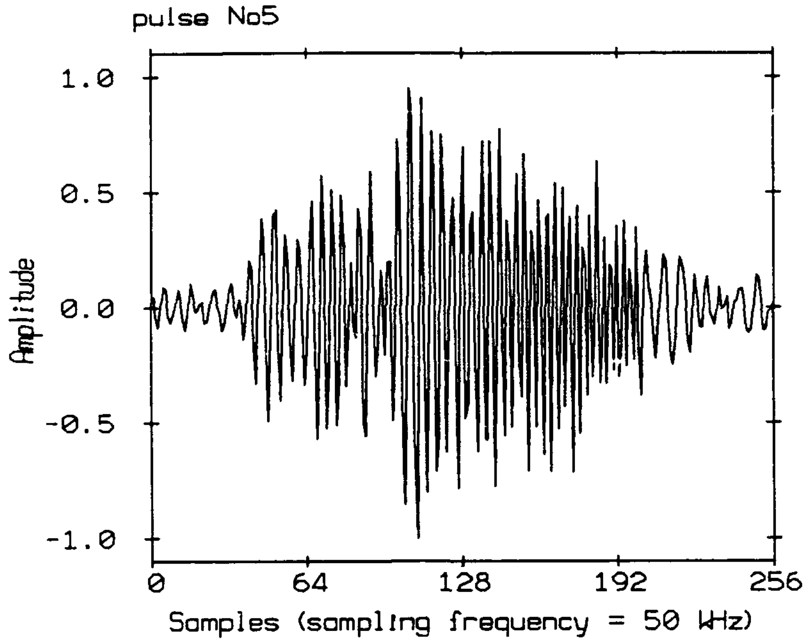
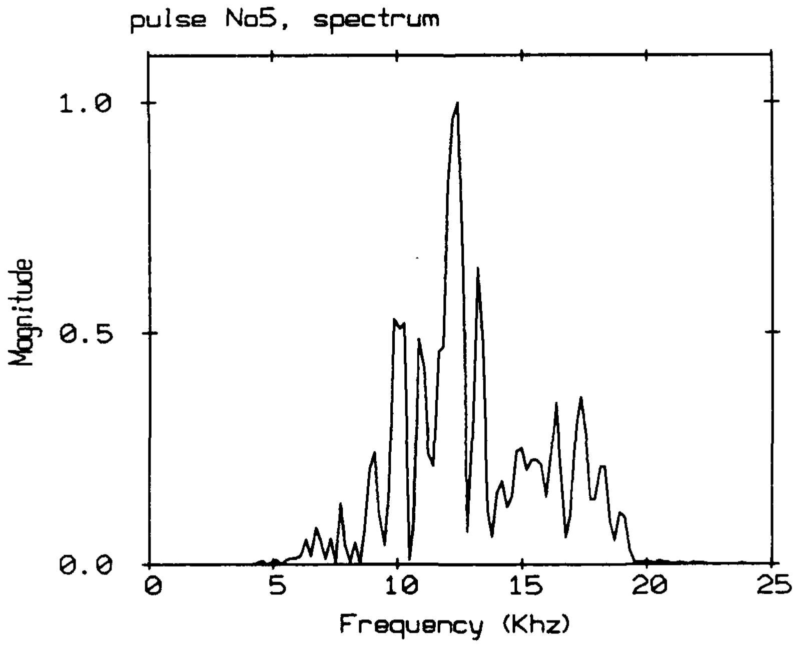
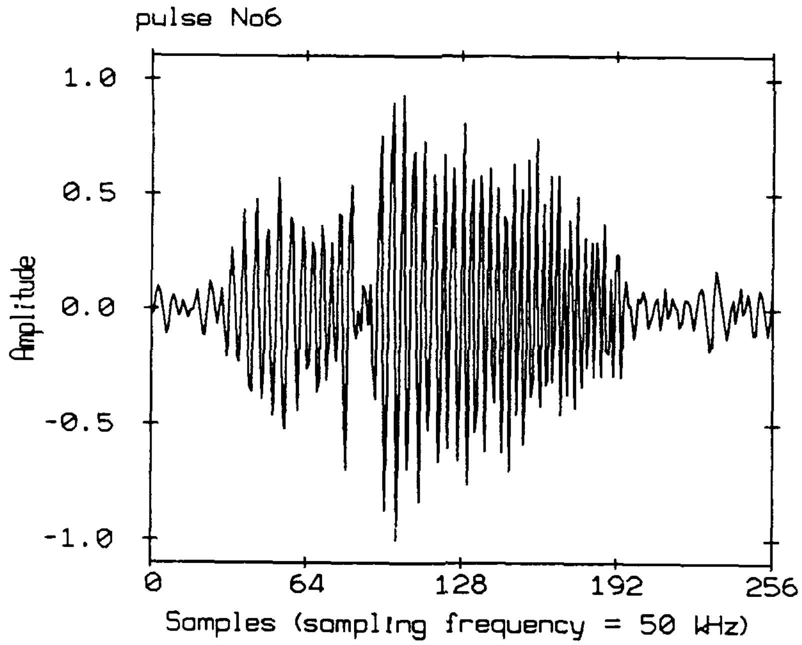
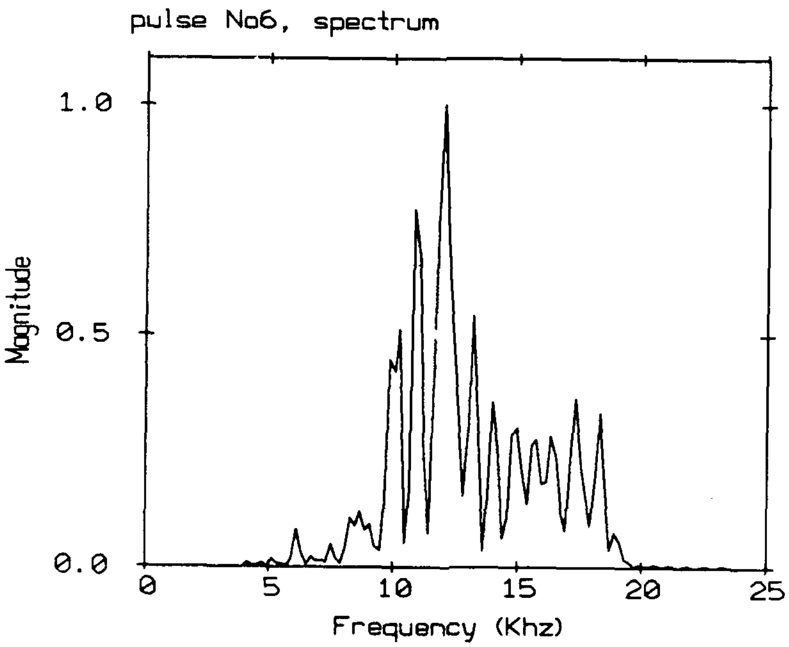


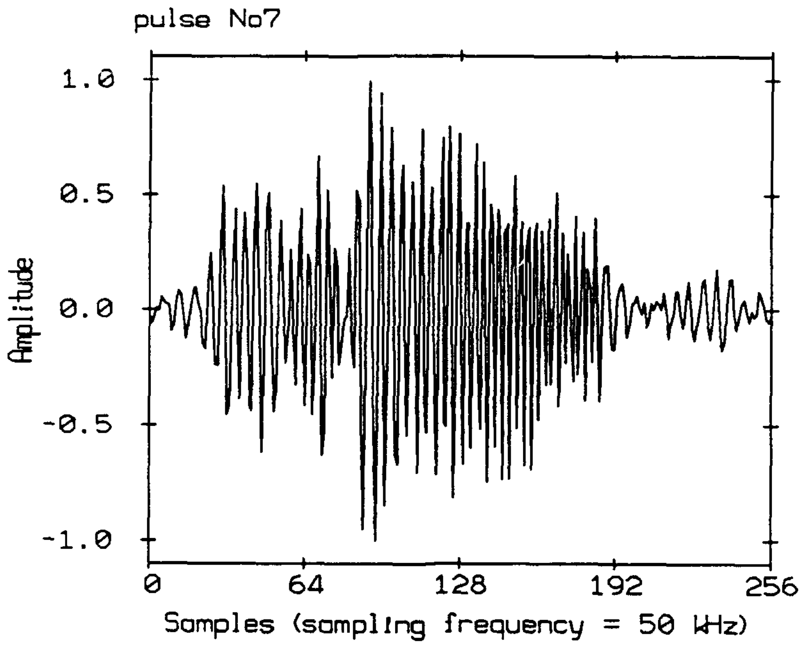


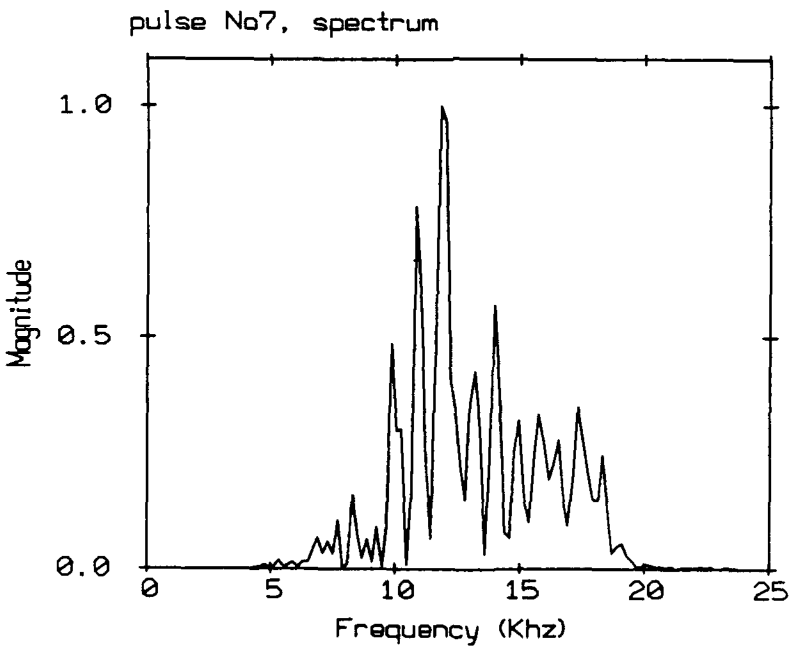
171607.1.ch2 , pulse No5





171607.1.ch2 , pulse No6





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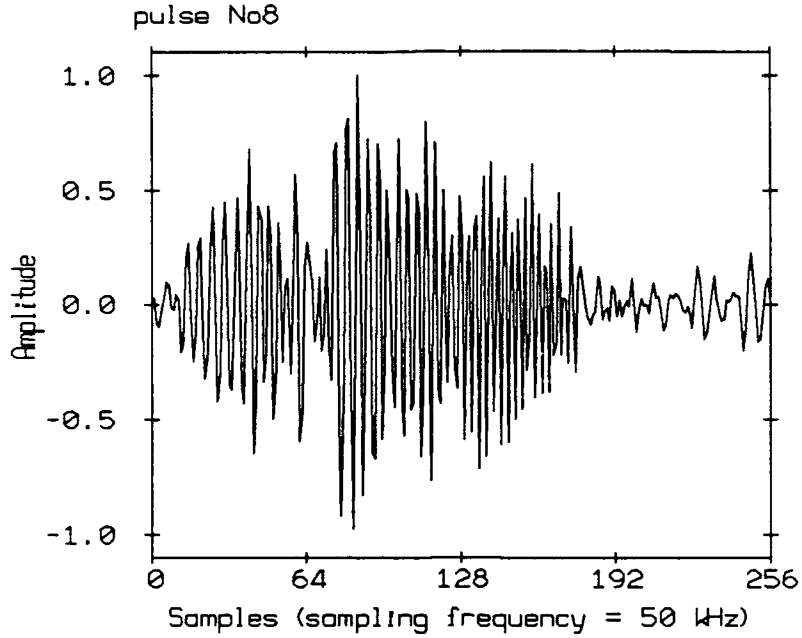

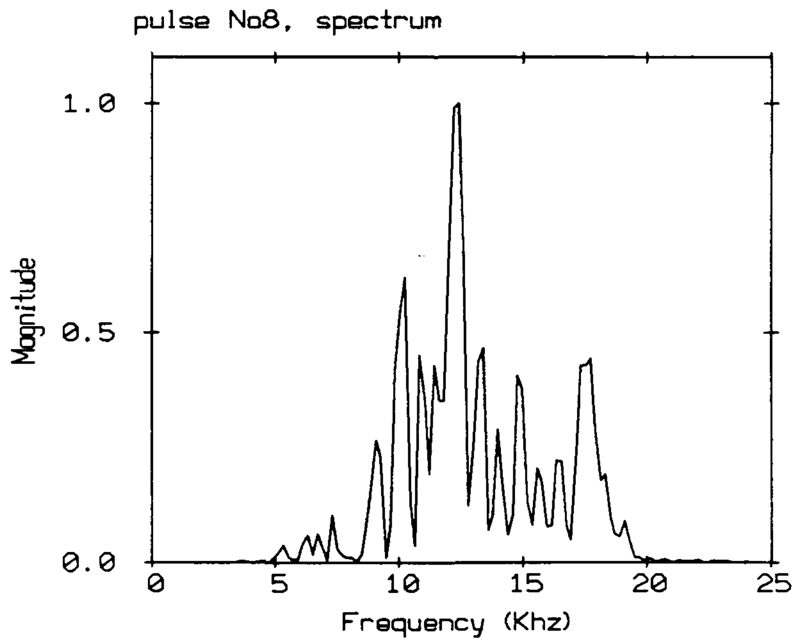

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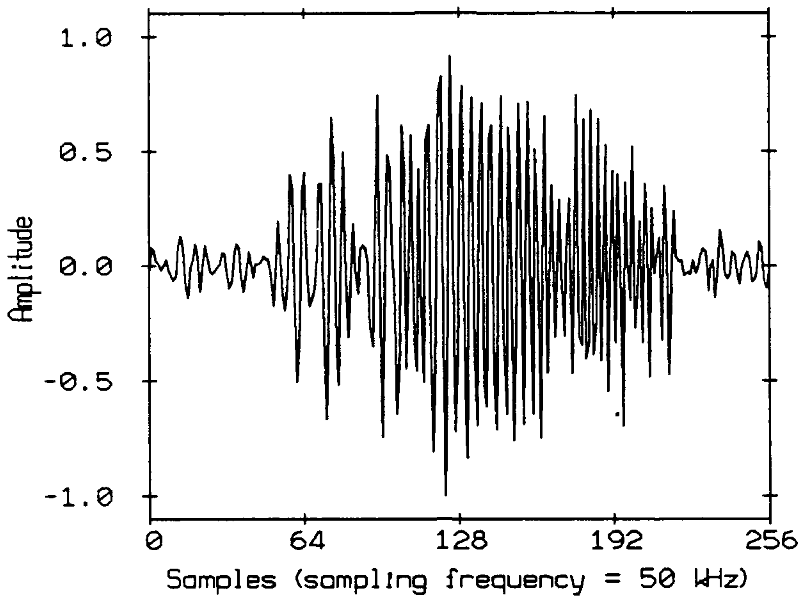
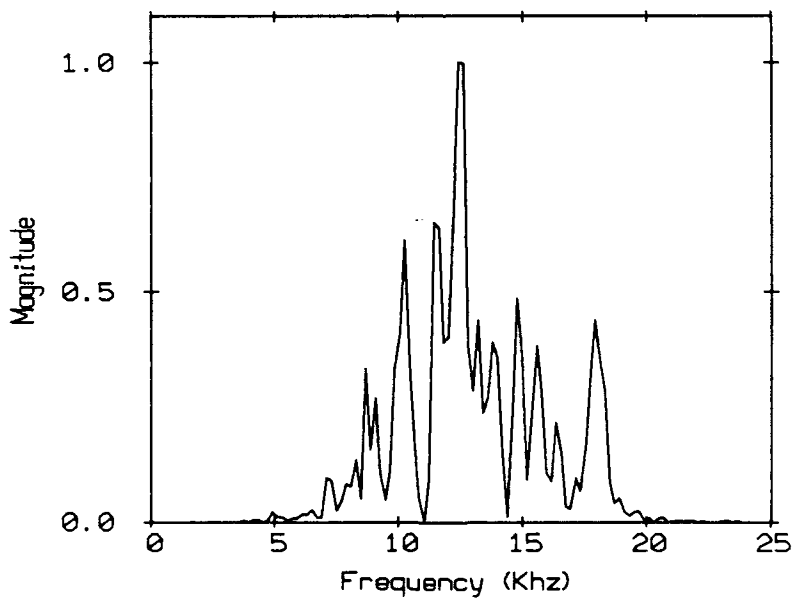
pulse No9



pulse No9, spectrum



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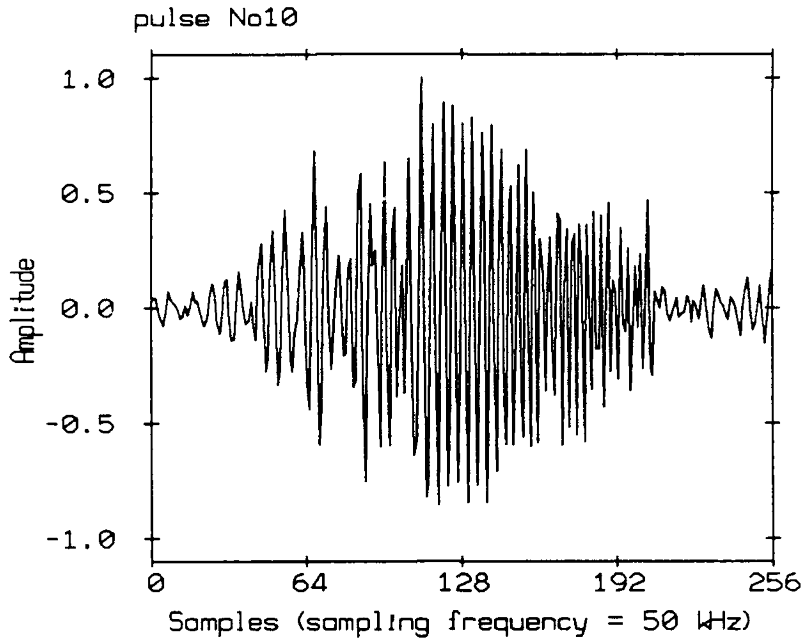
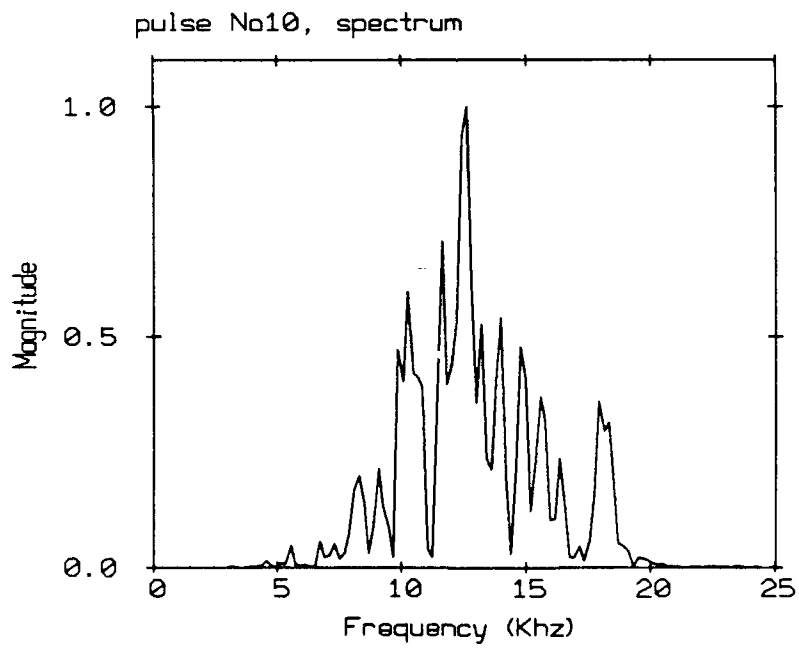
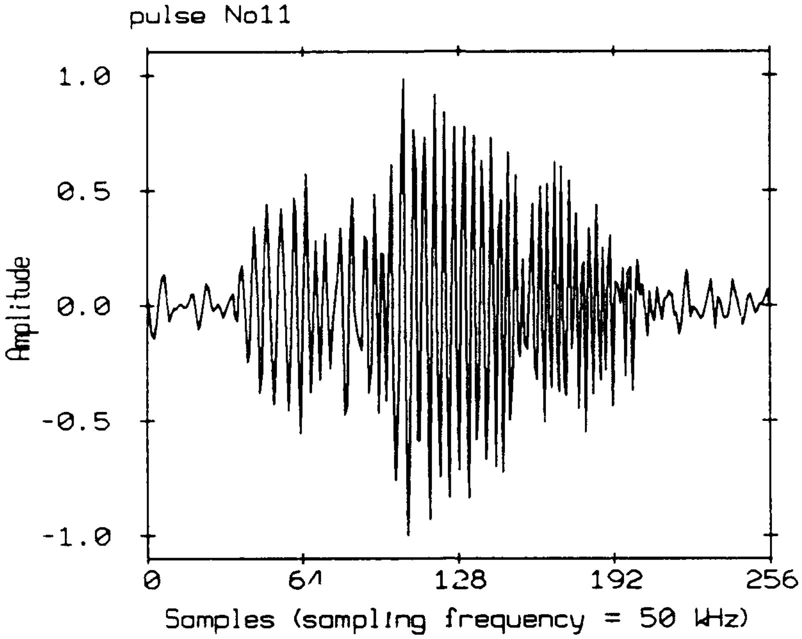
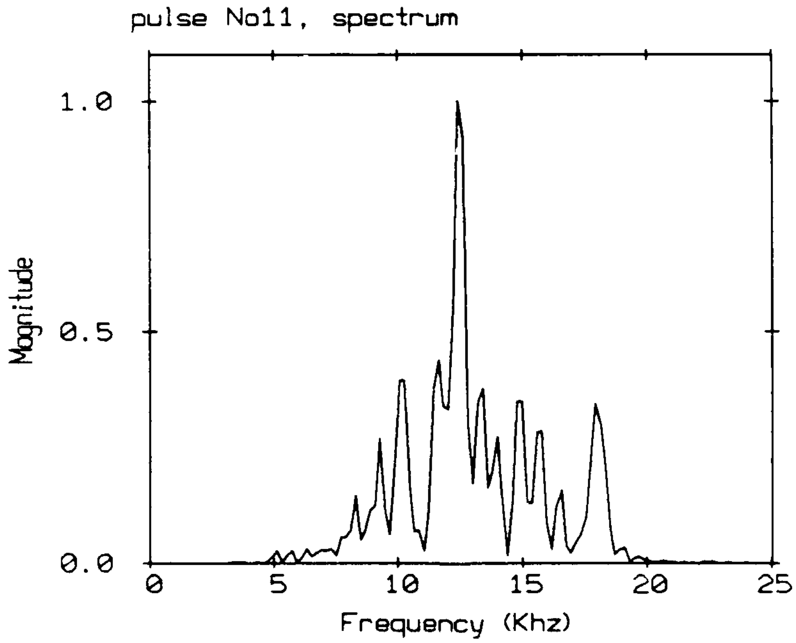


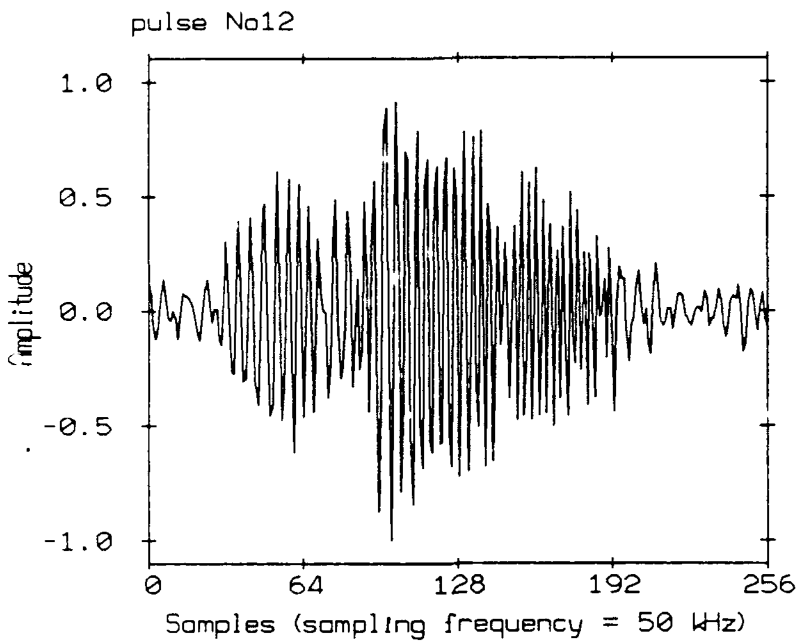


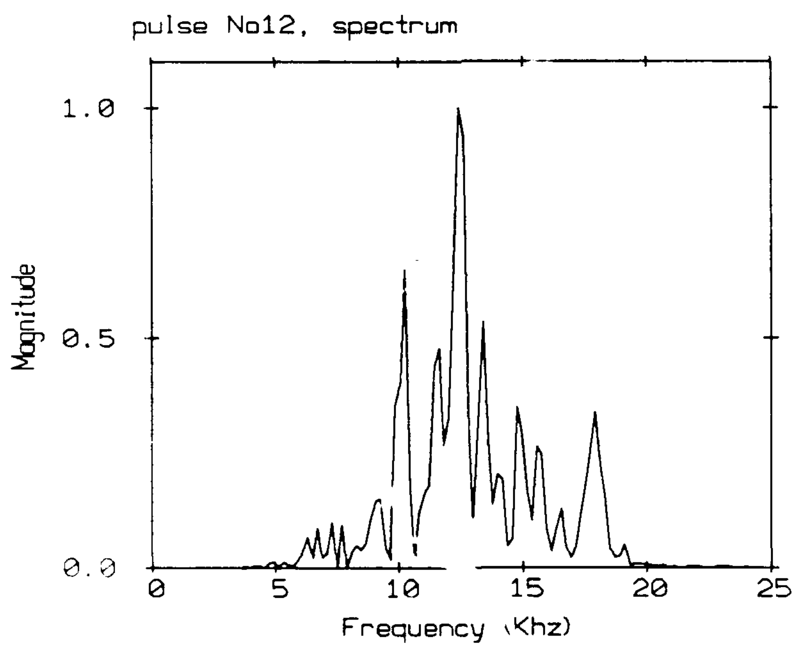
171607.1.ch2 , pulse No10



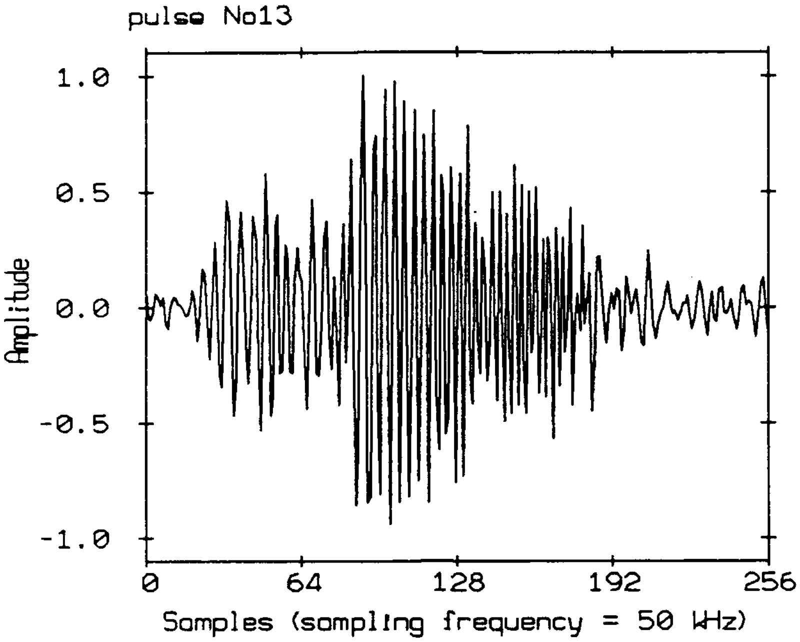


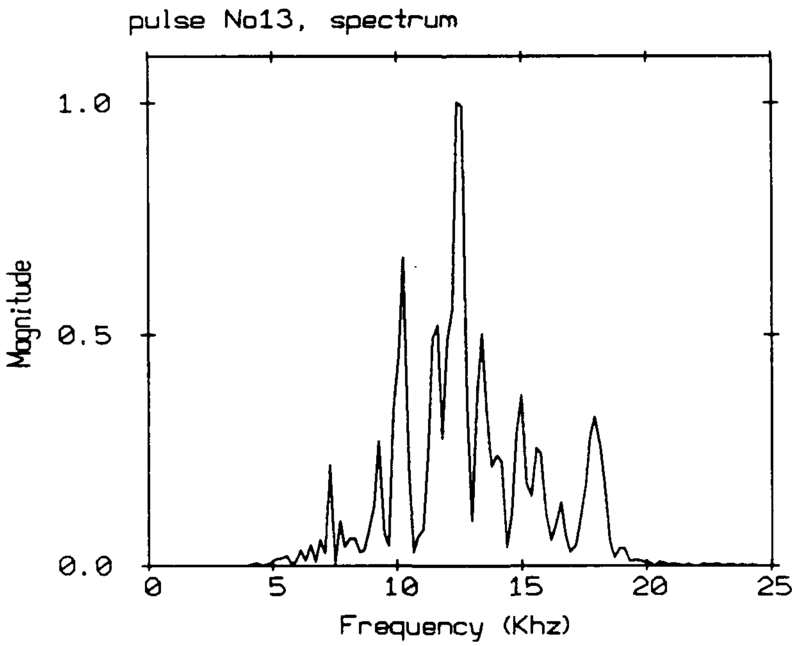
171607.1.ch2 , pulse No11





171607.1.ch2 , pulse No12





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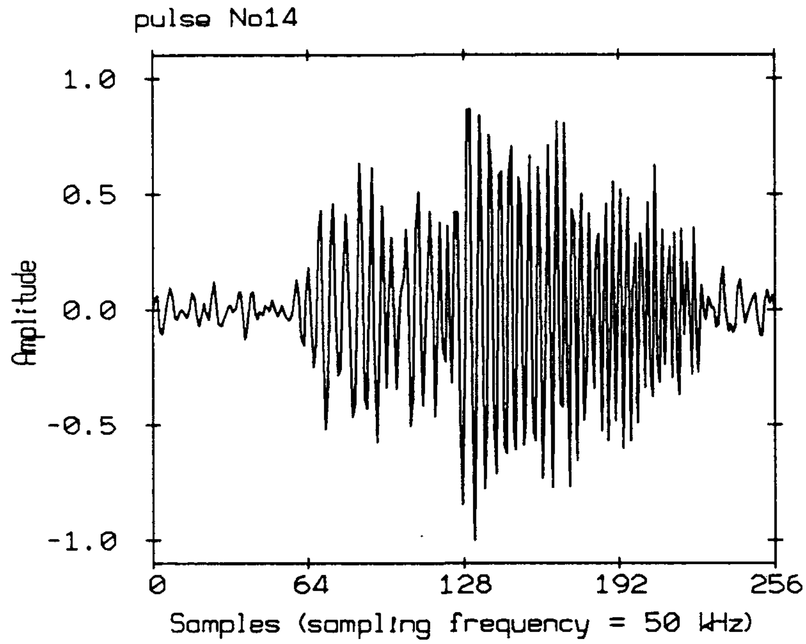
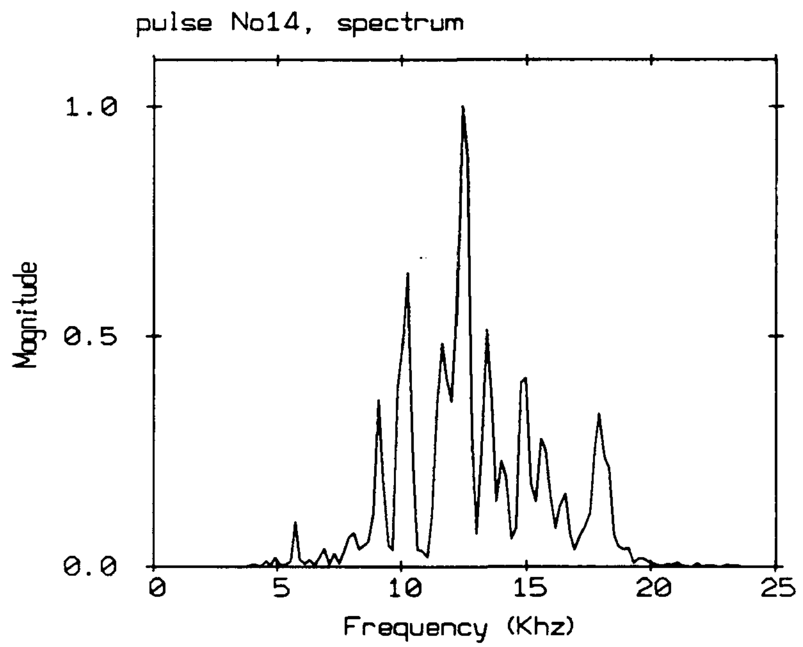
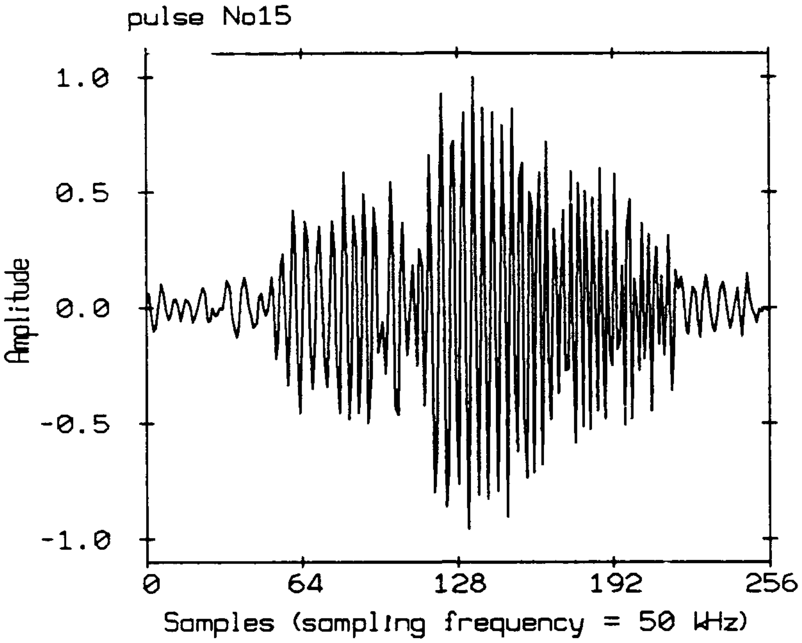
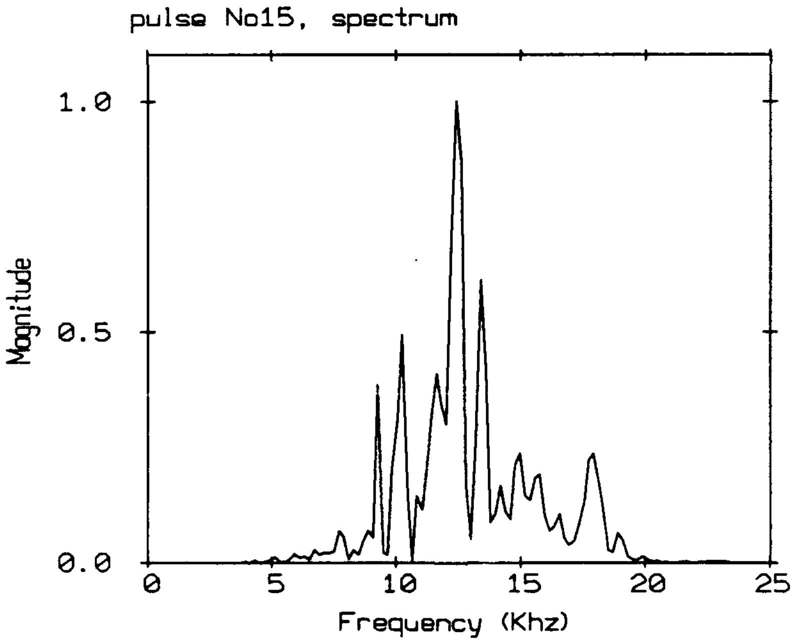


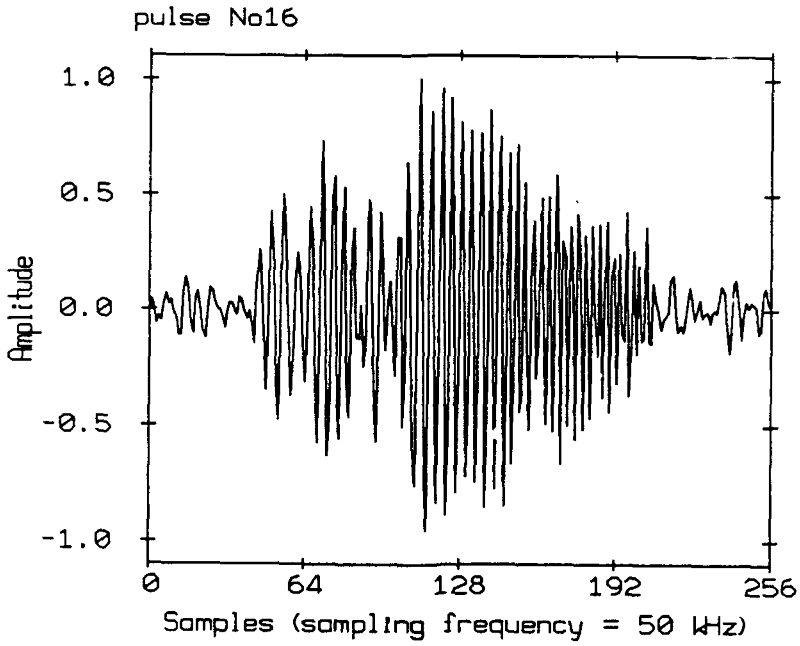


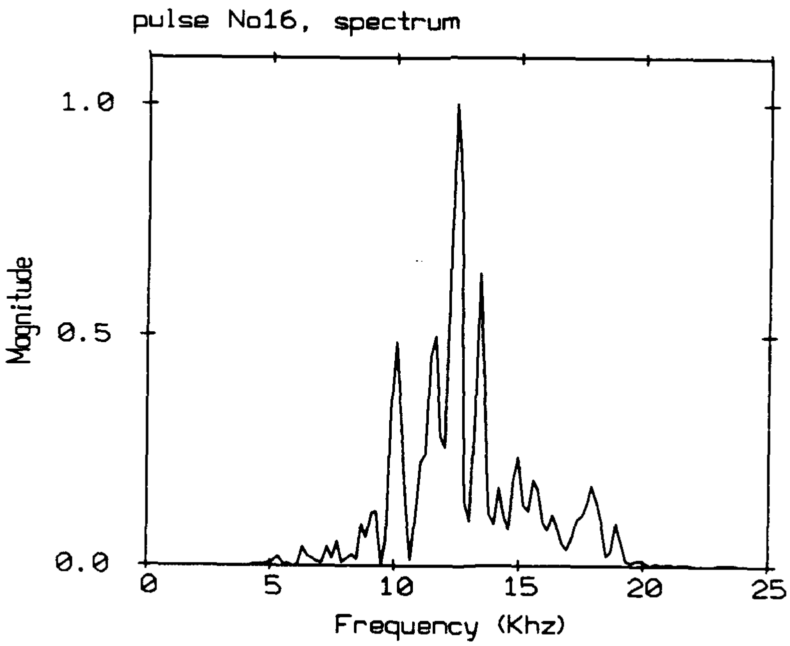
171607.1.ch2 , pulse No14





171607.1.ch2 , pulse No15





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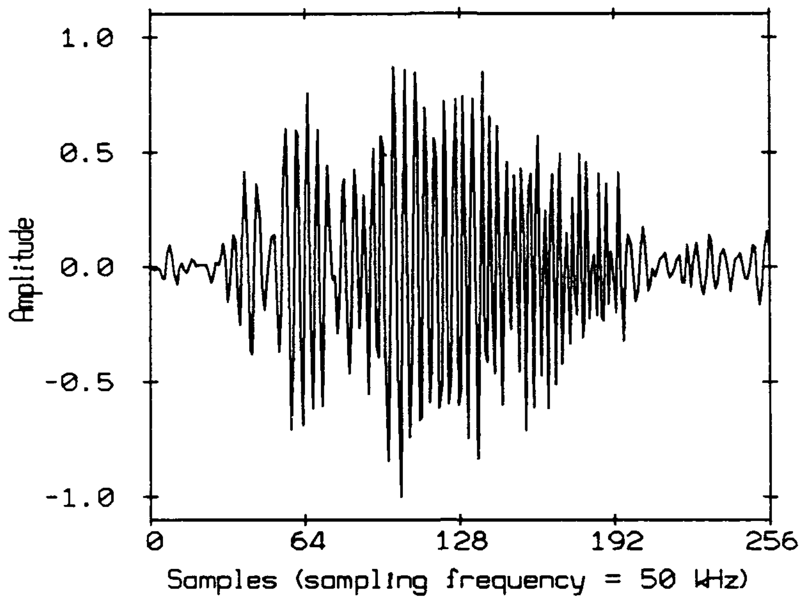
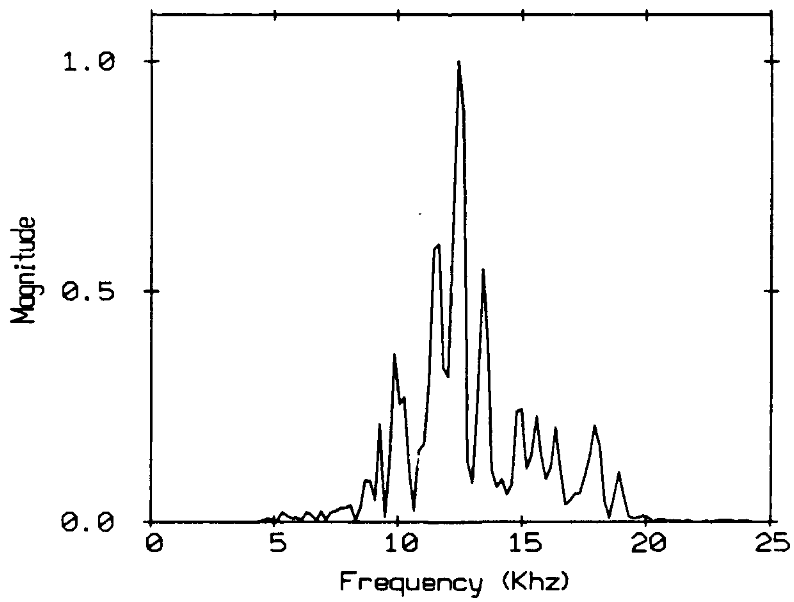
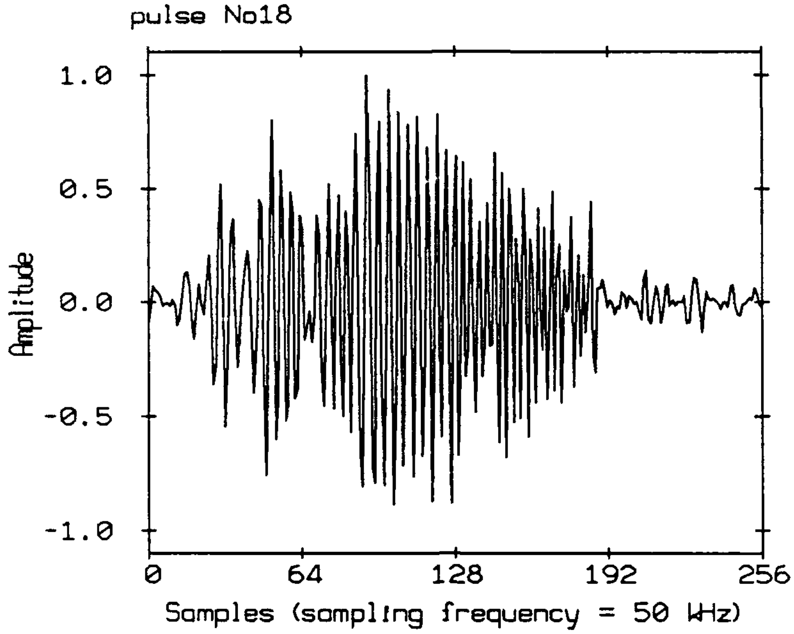
pulse No17

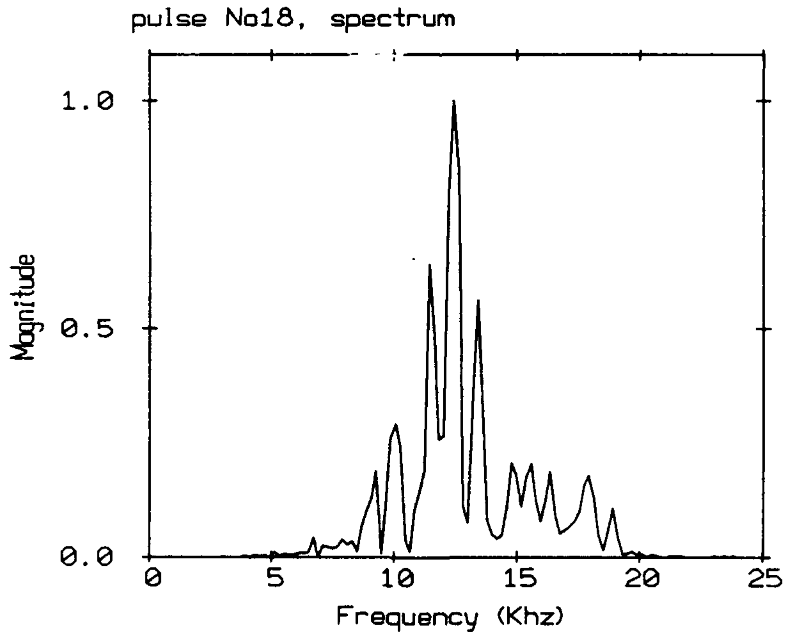


pulse No17, spectrum



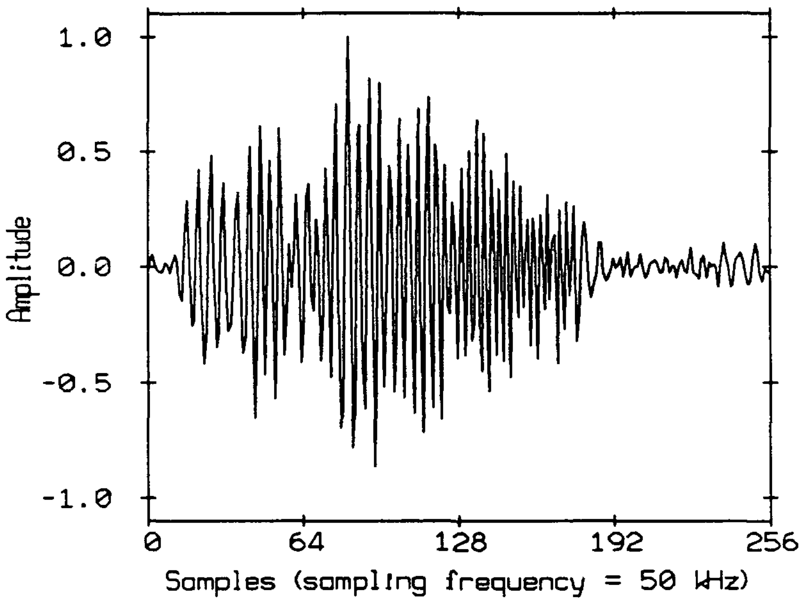
171607.1.ch2 , pulse No17



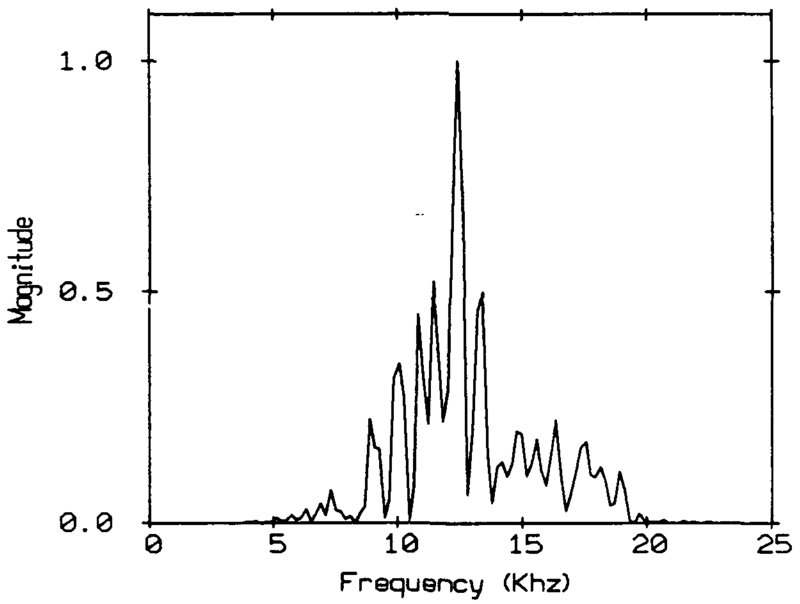


171607.1.ch2 , pulse No18

pulse No19



pulse No19, spectrum



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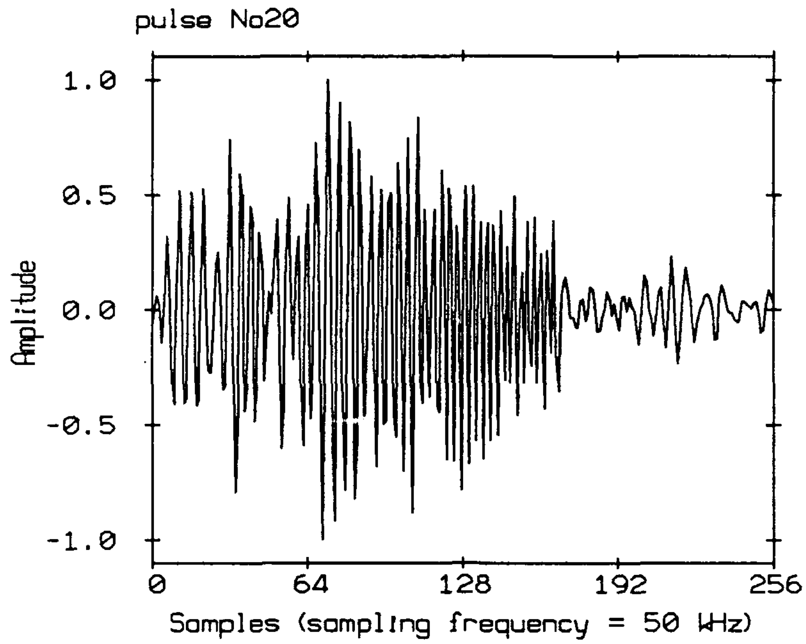
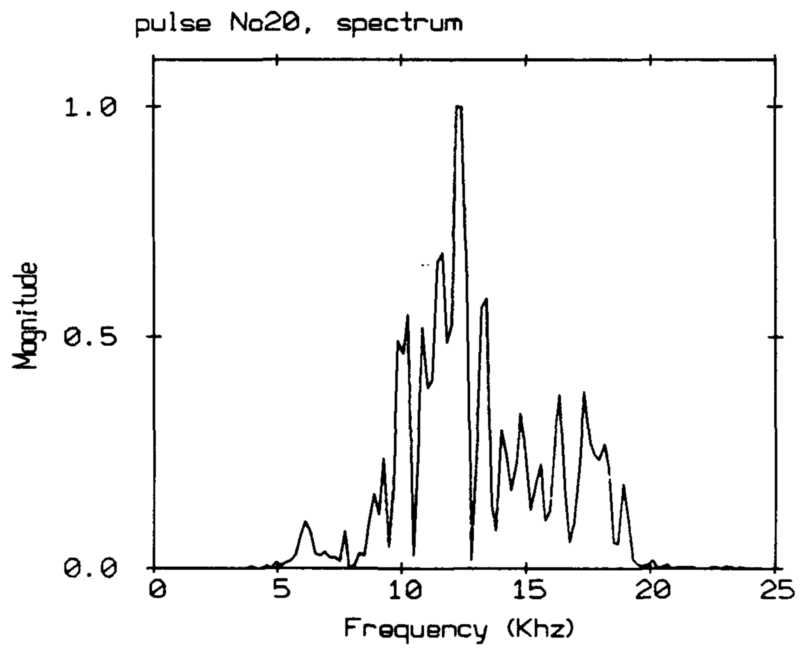
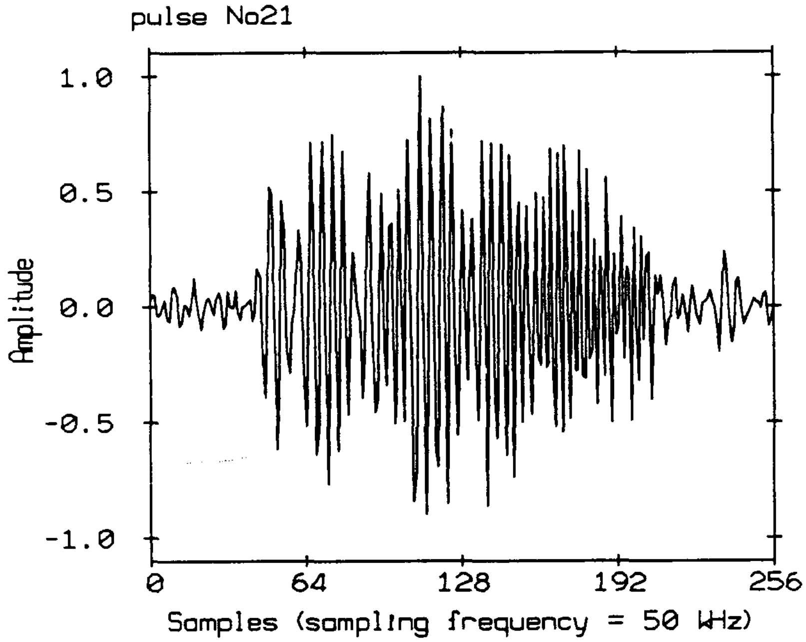
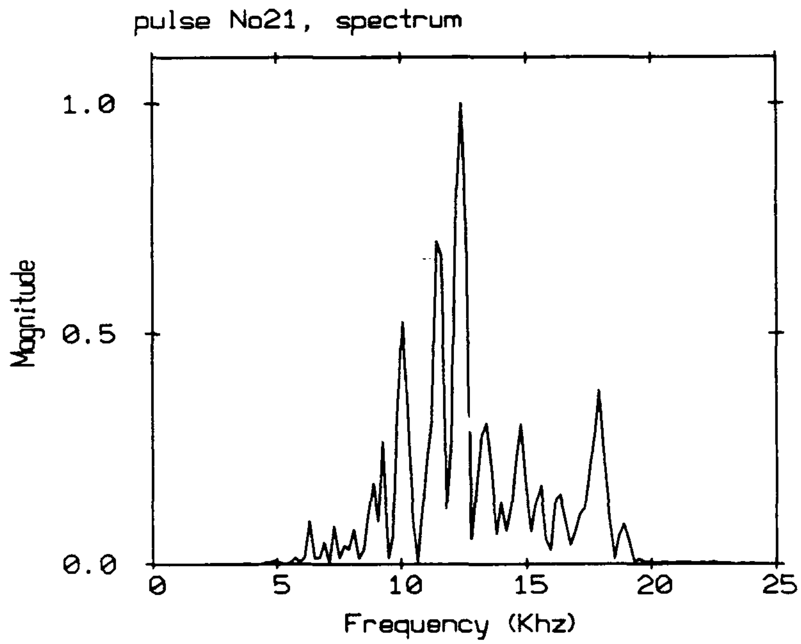




171607.1.ch2 , pulse No20





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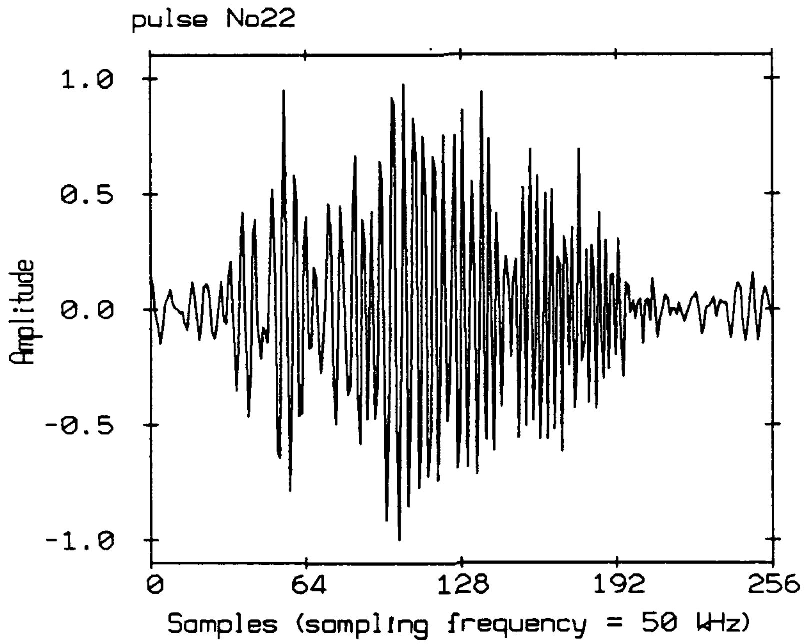

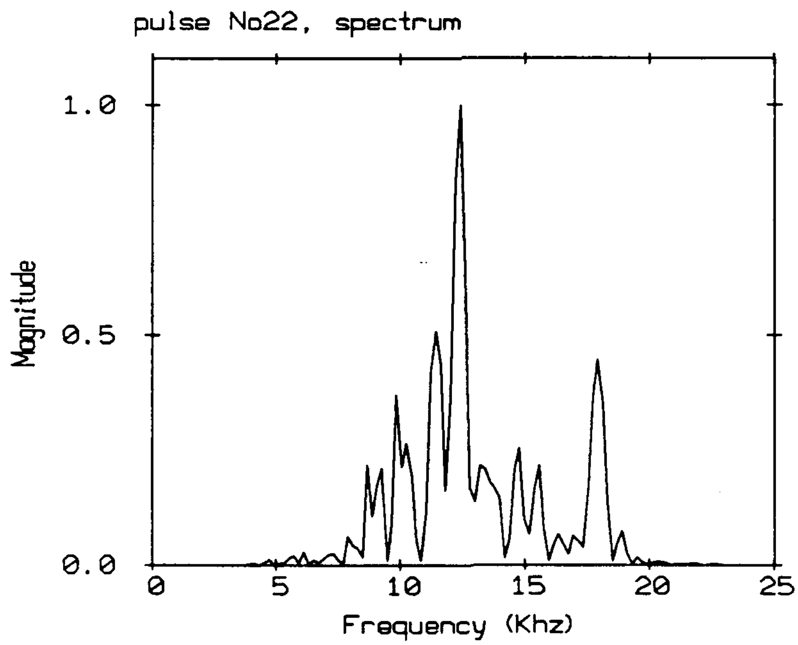

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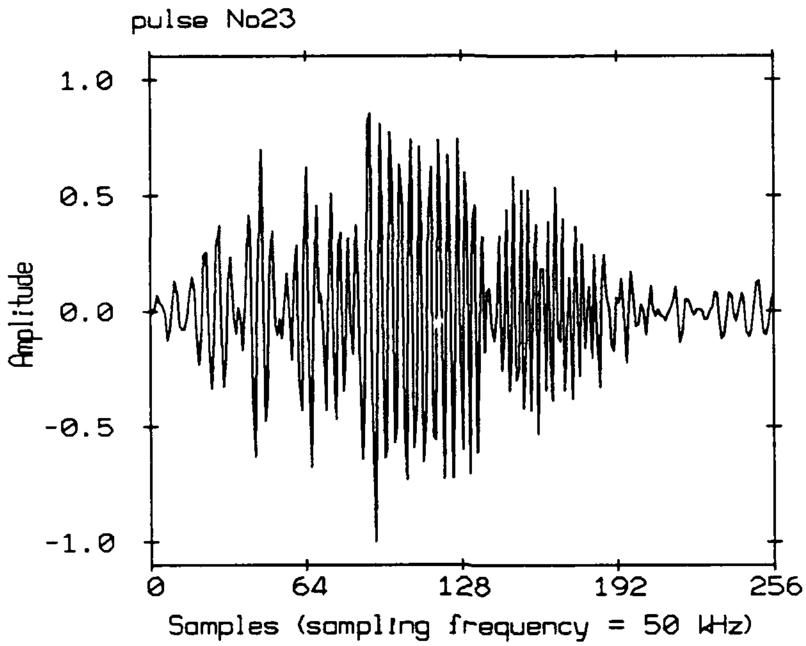

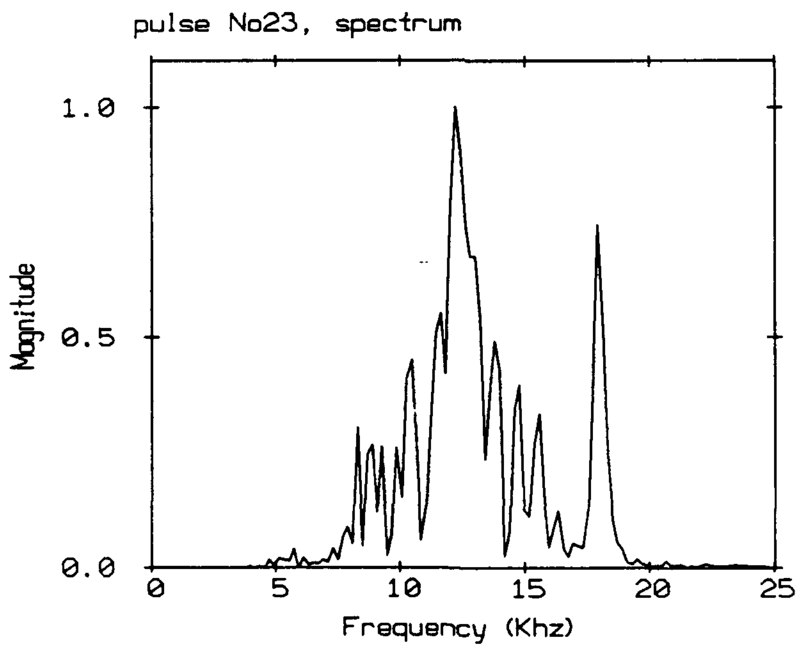

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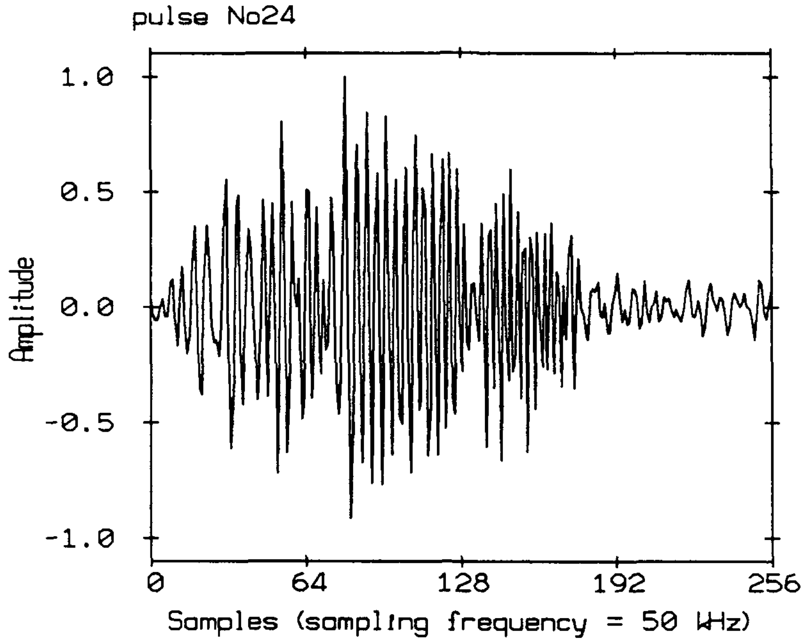

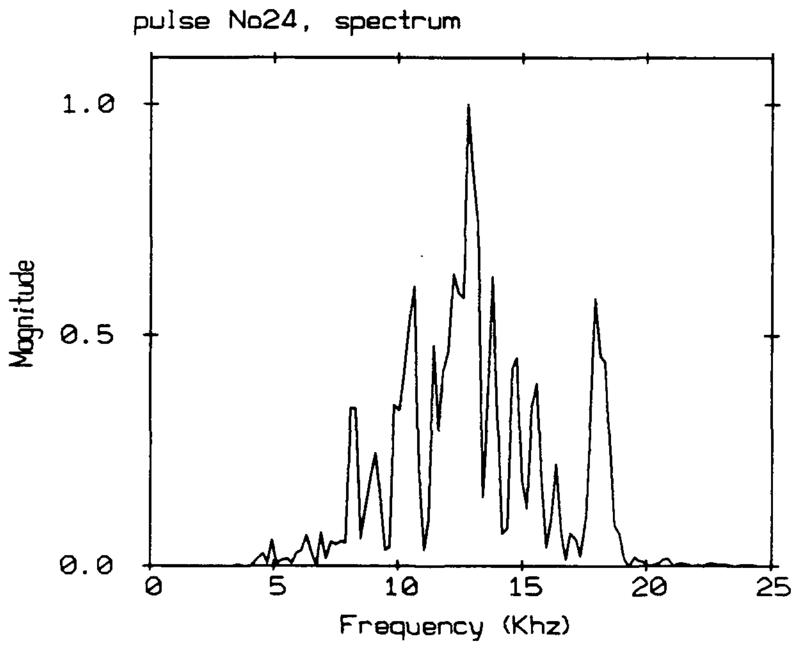

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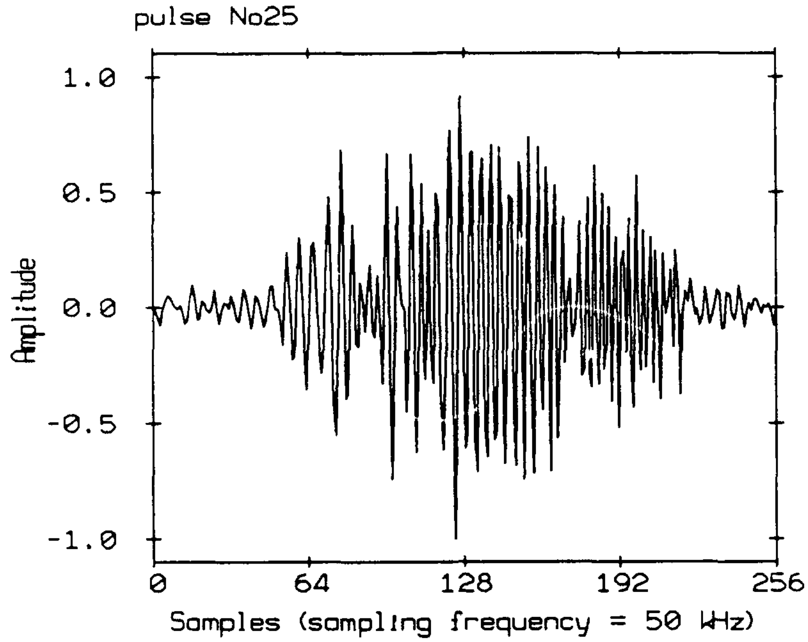

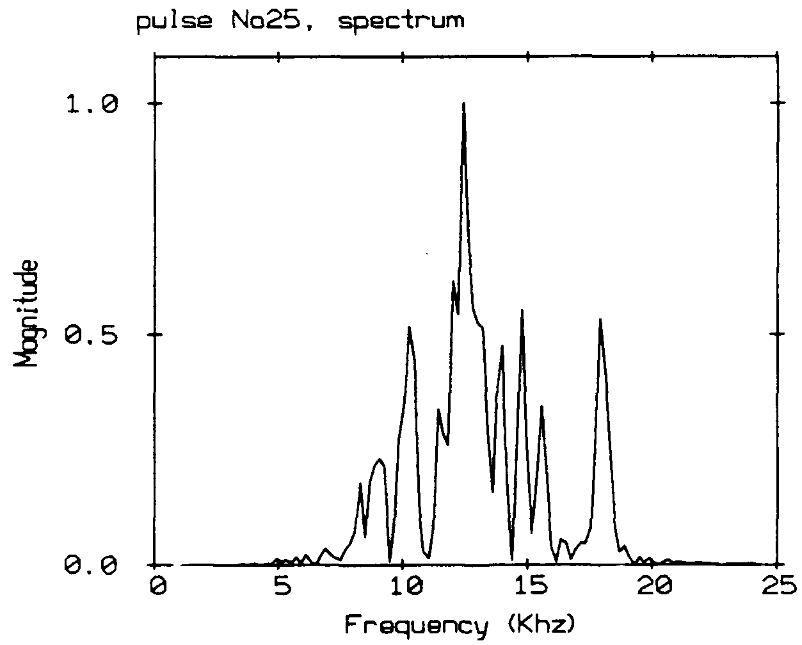

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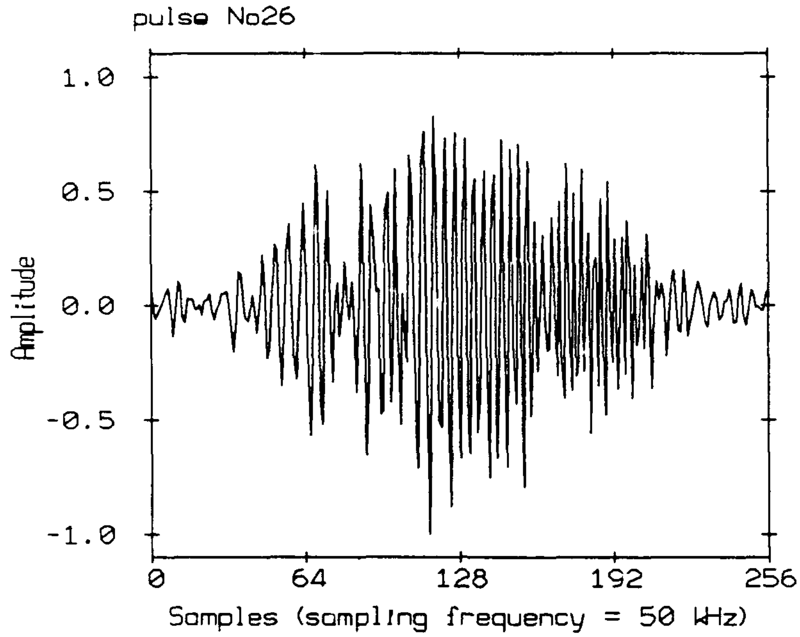

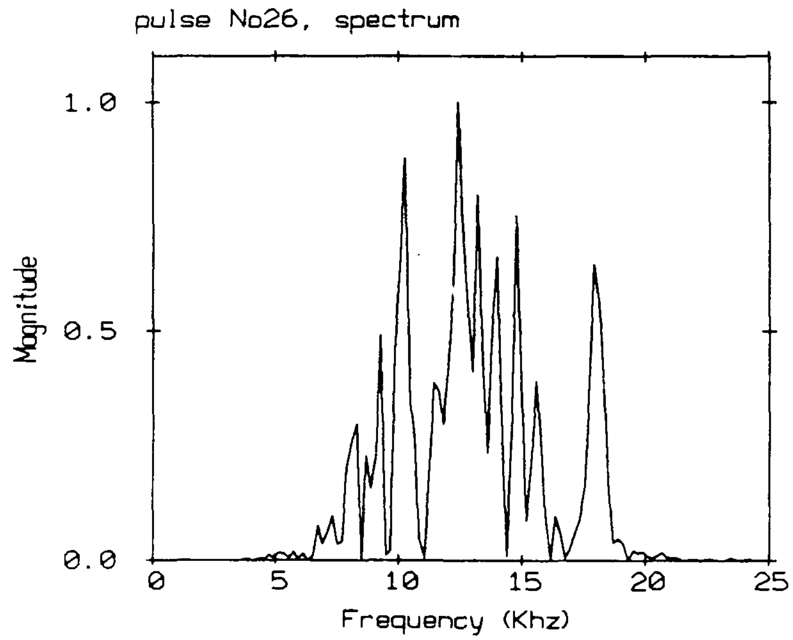

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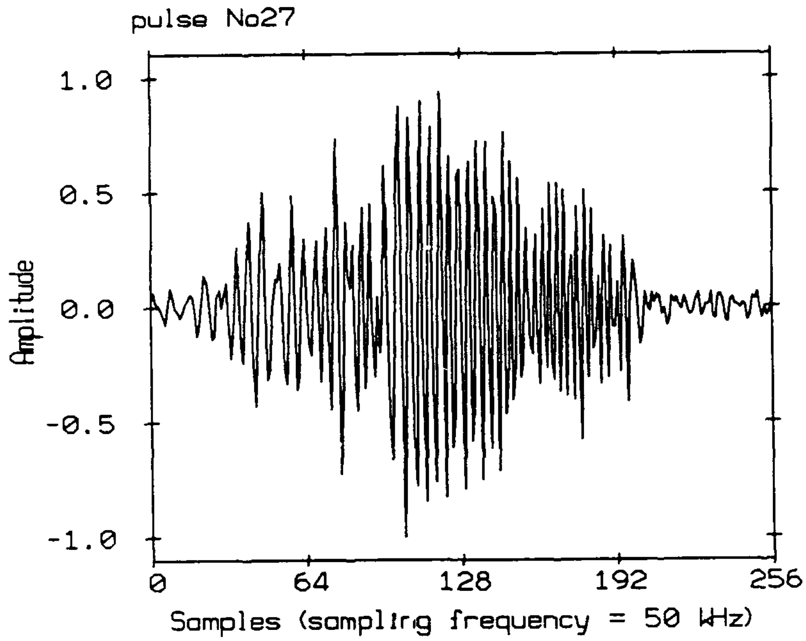

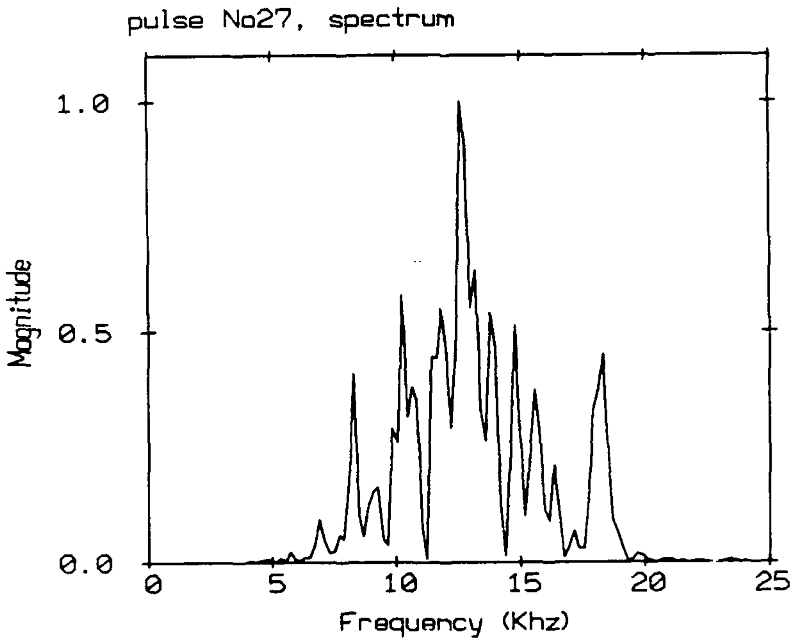

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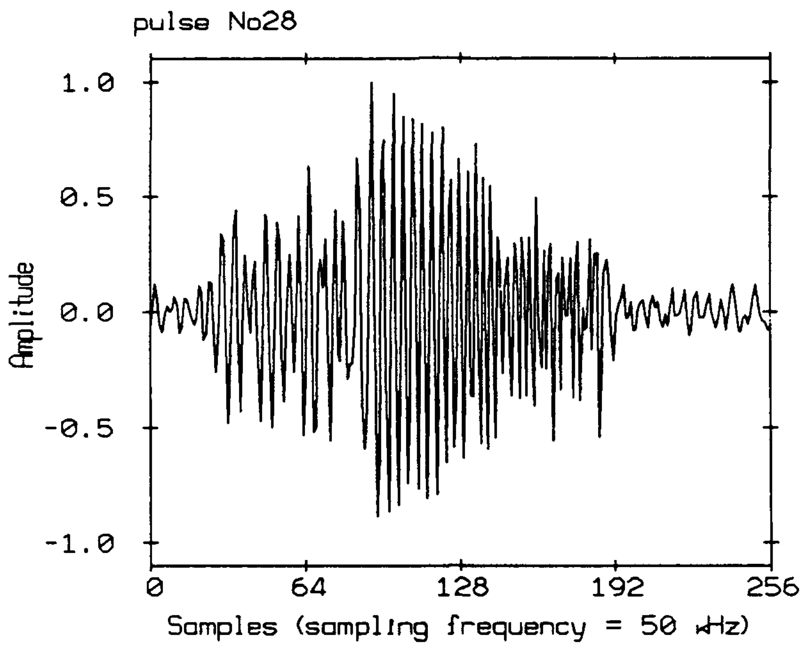
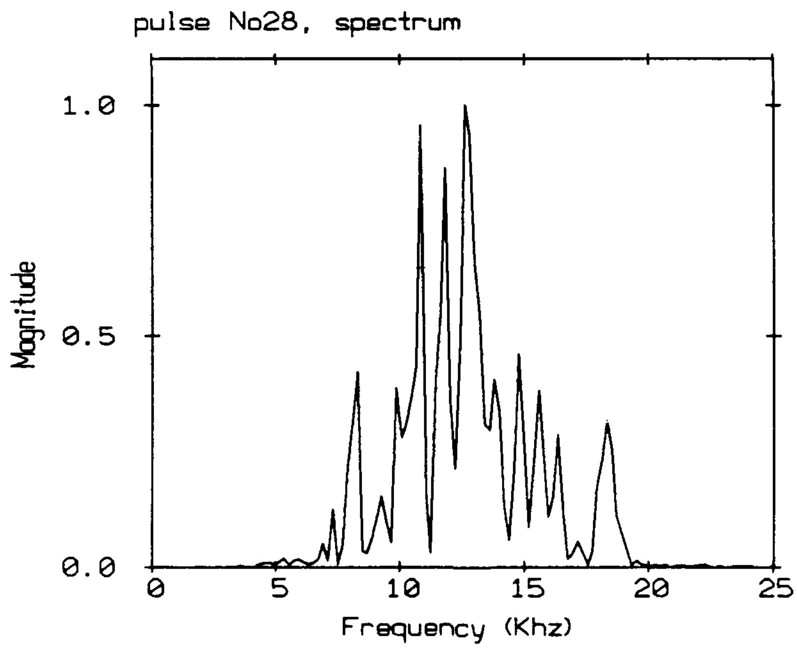




171607.1.ch2 , pulse No28

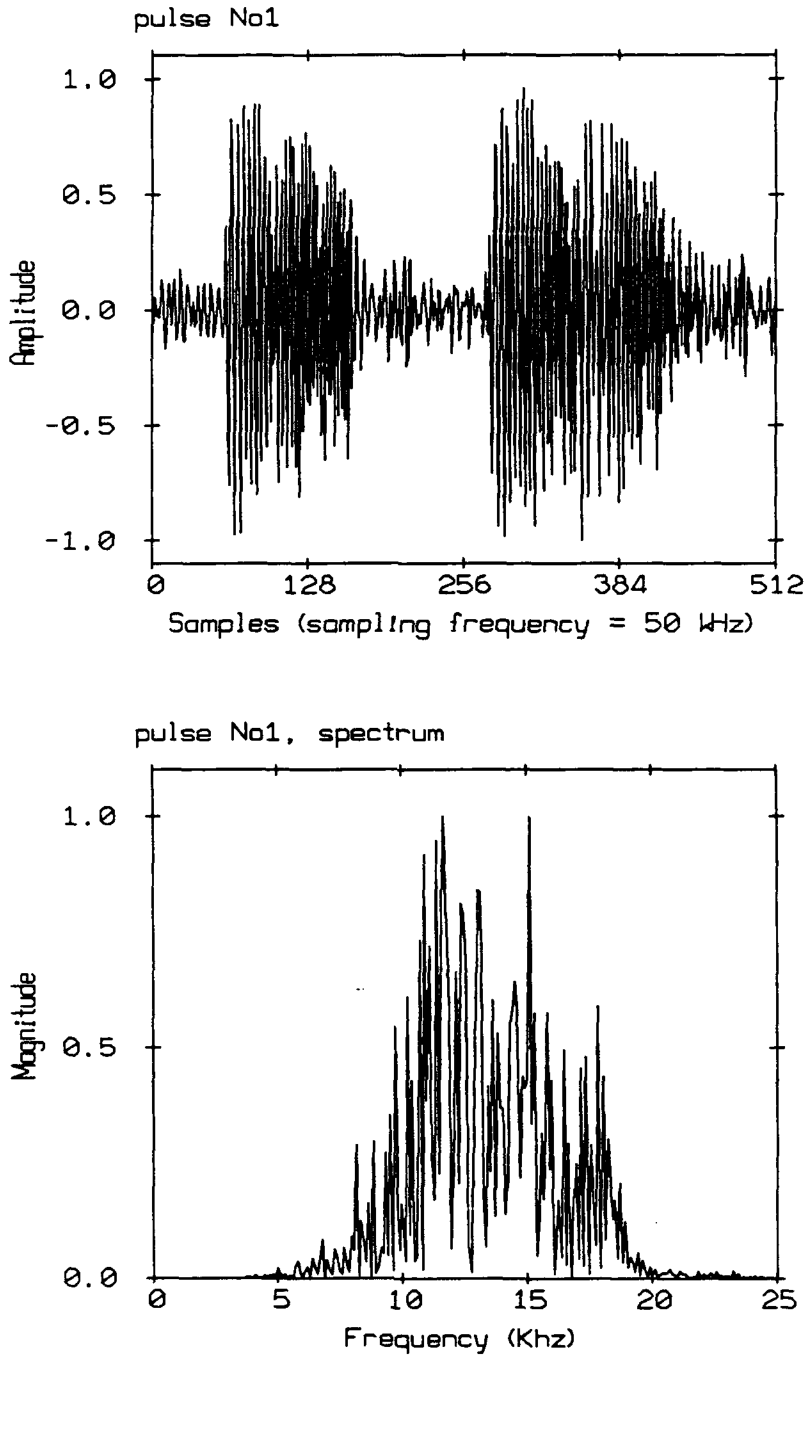
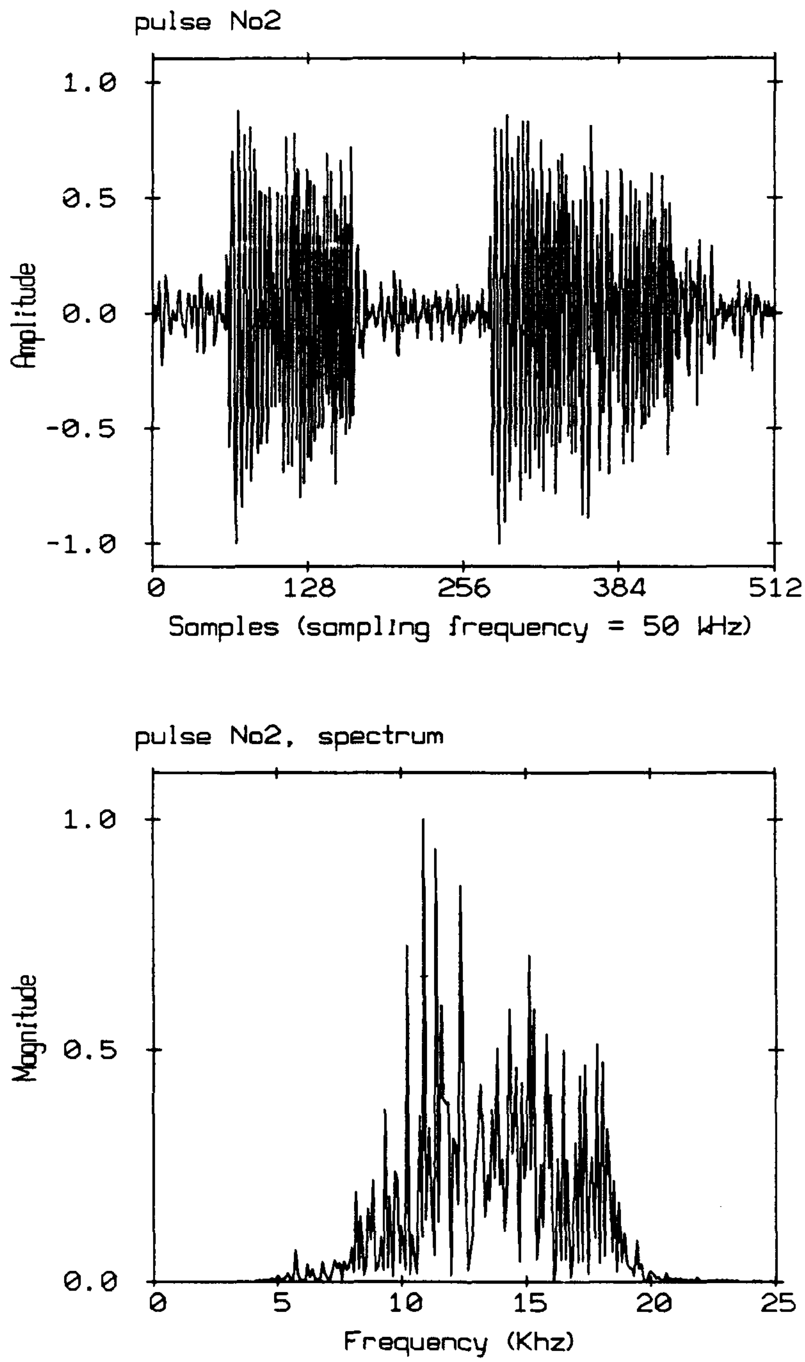


Figure 3.35-3.62. The direct signal and the first multipath of the 28 2msec chirps as received by sonobuoy No 4.



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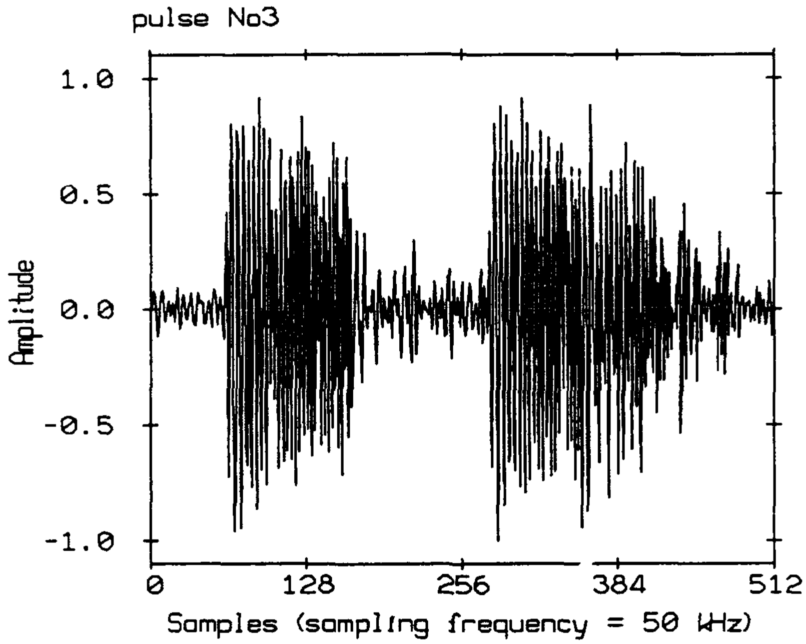

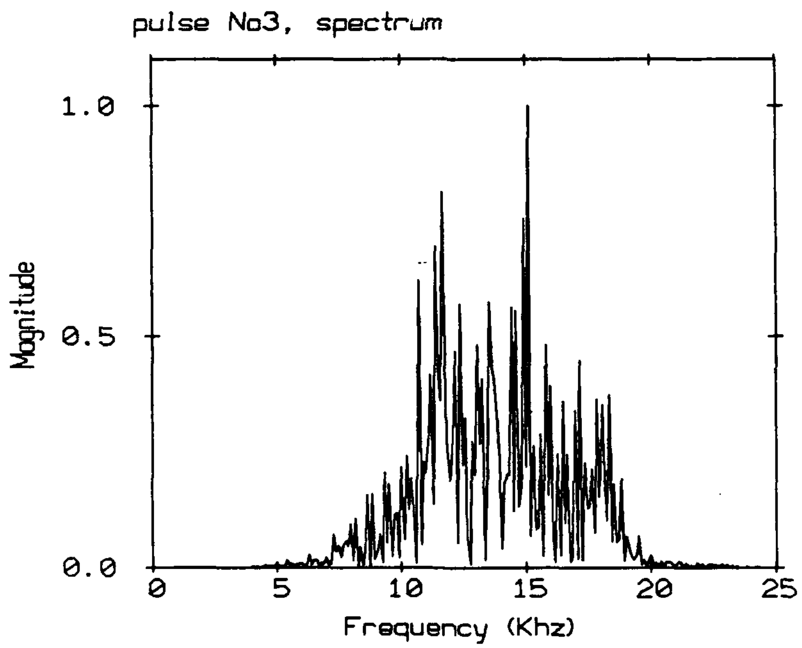

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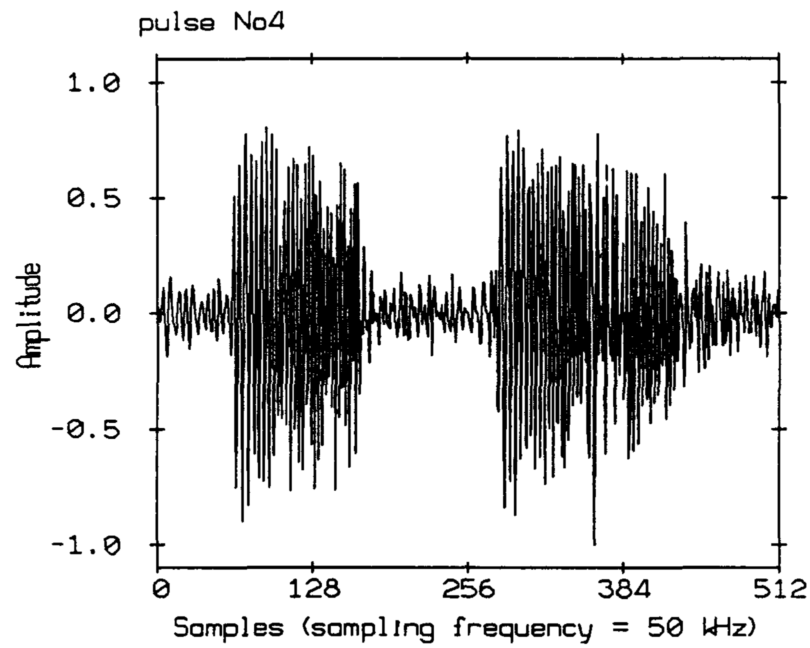

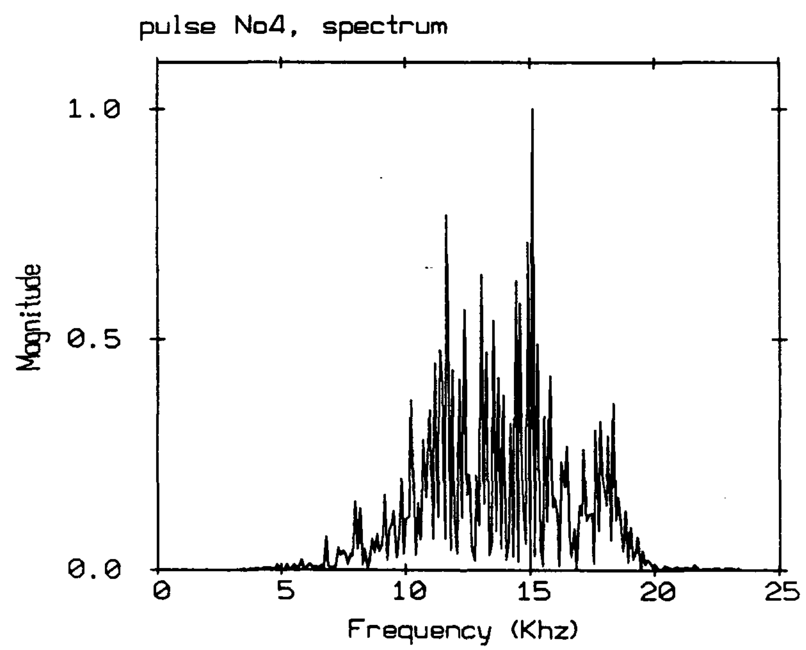

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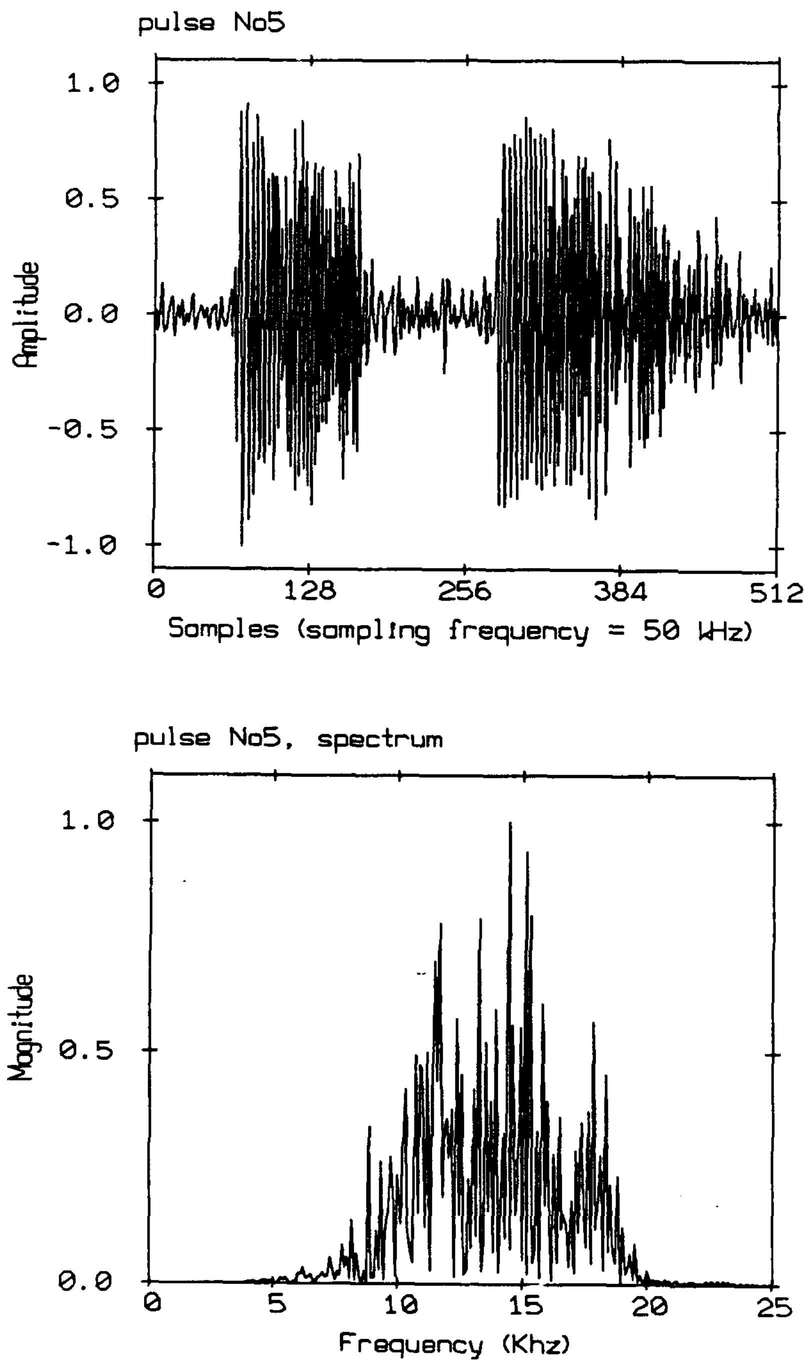
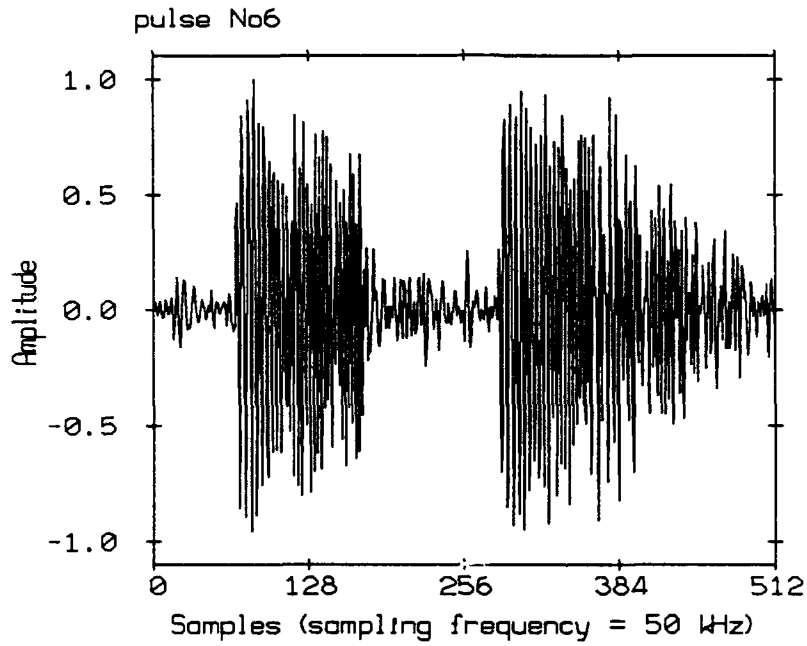
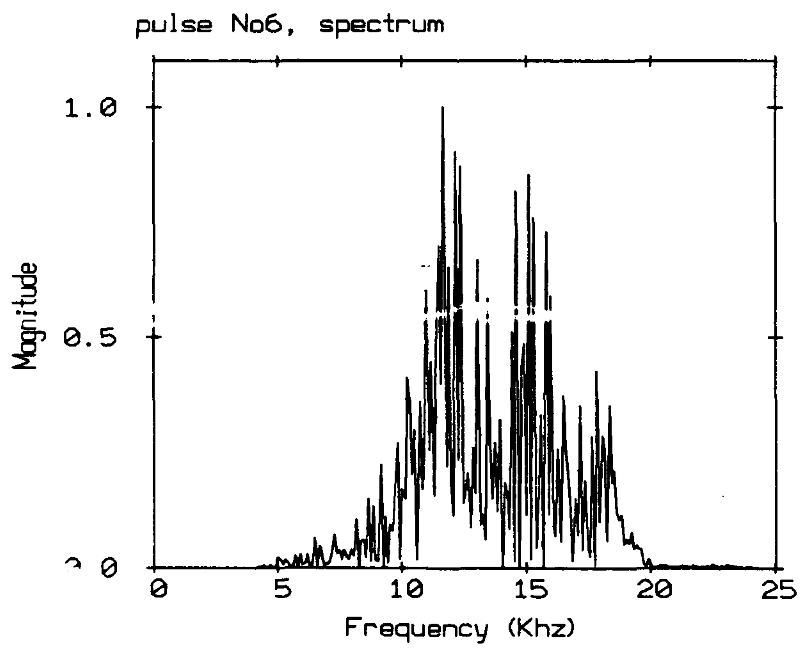
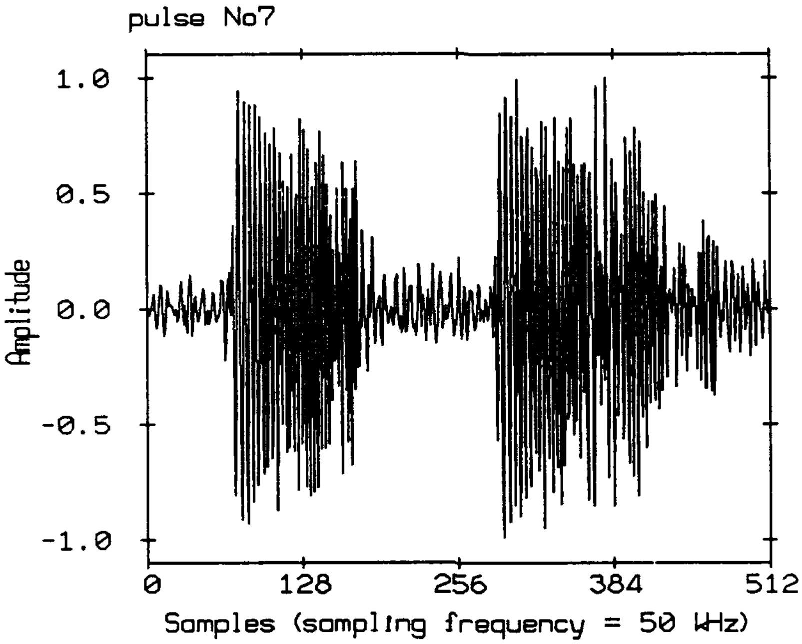


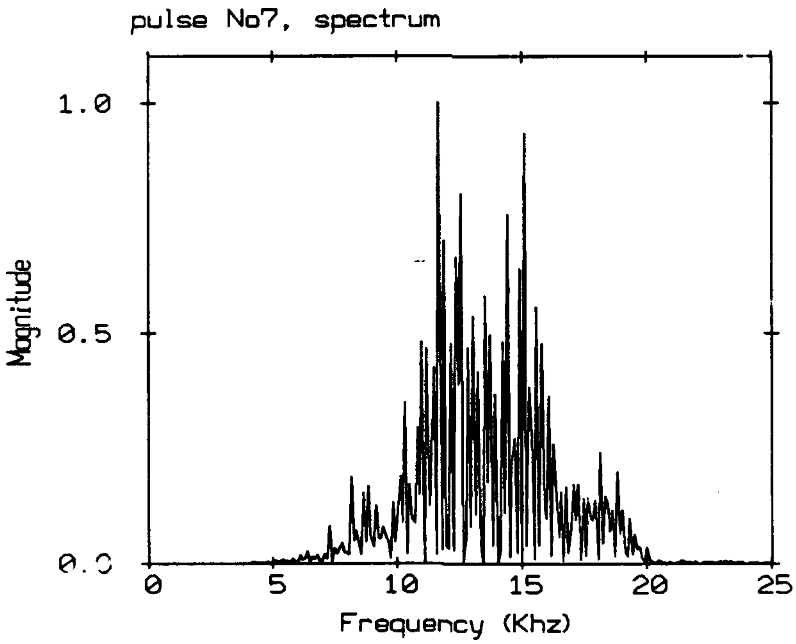
171607.1.ch4 , pulse No5



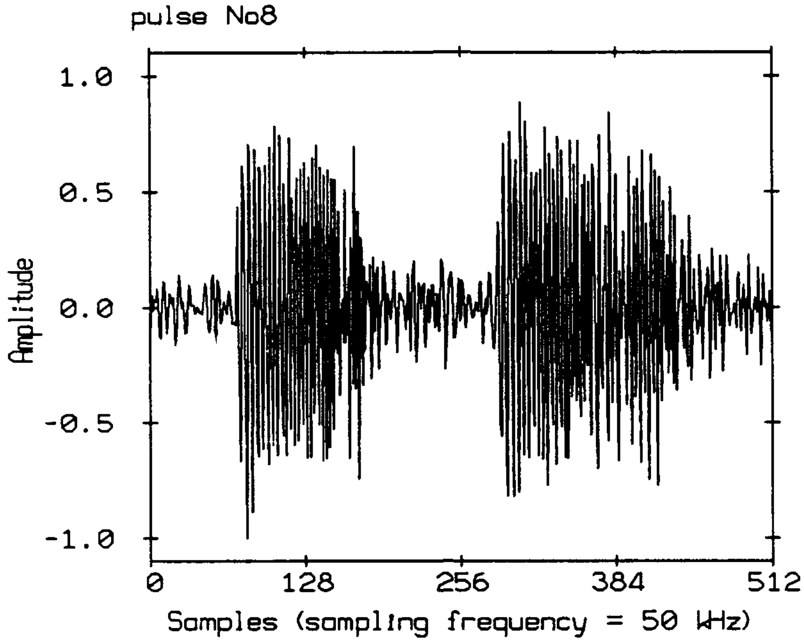


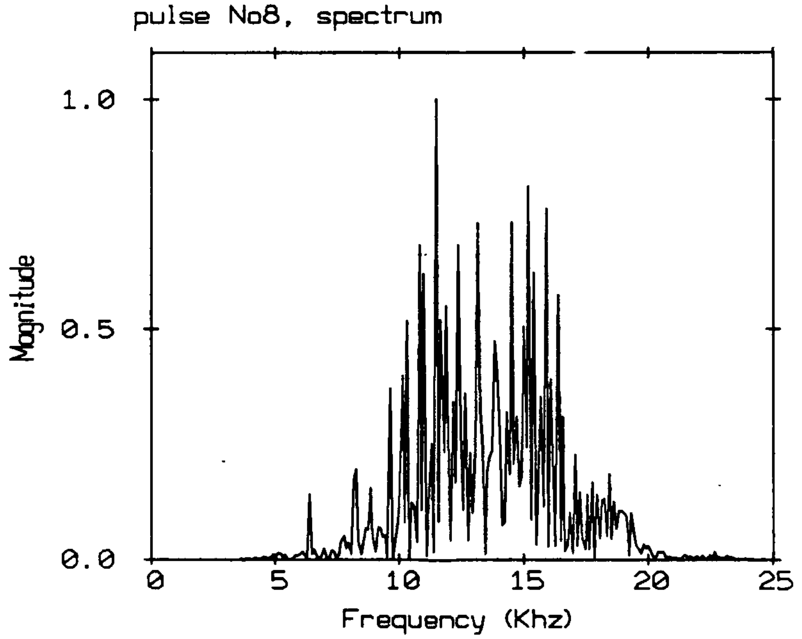
171607.1.ch4 , pulse No6



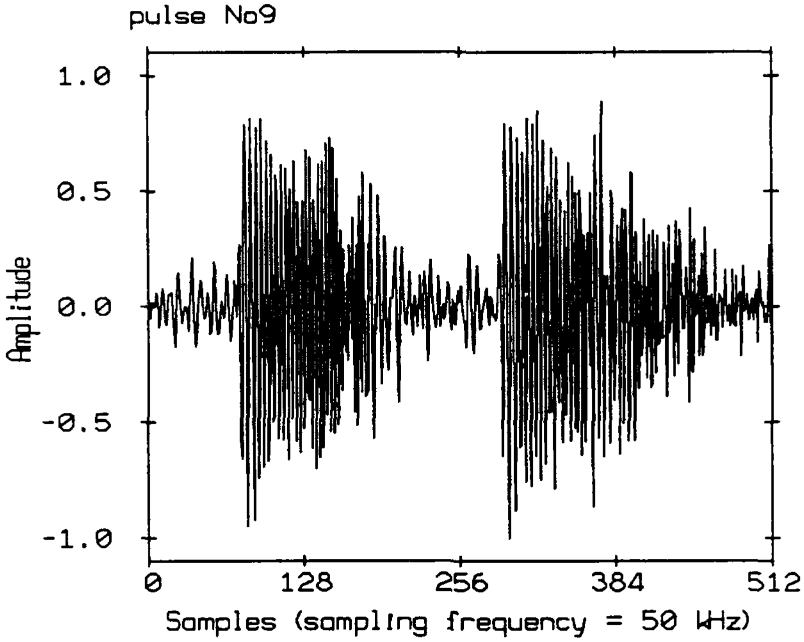


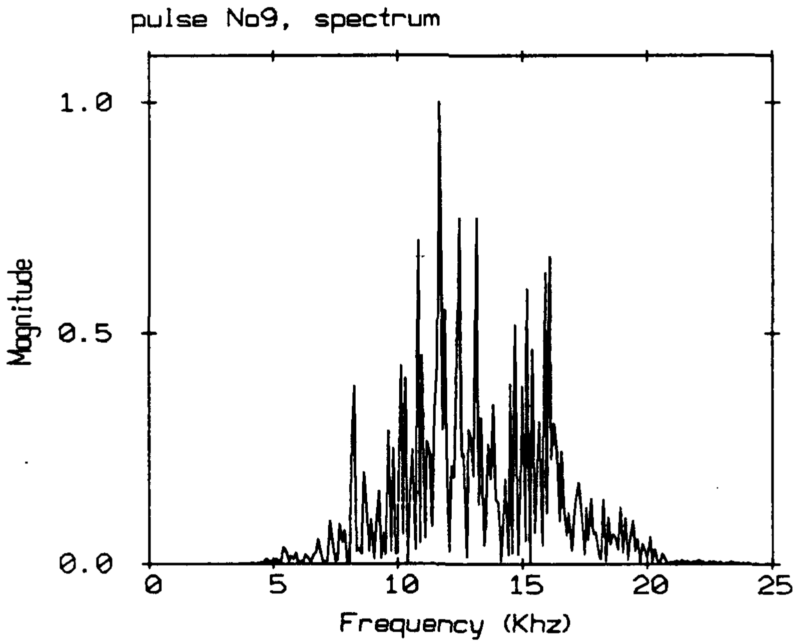
171607.1.ch4 , pulse No7



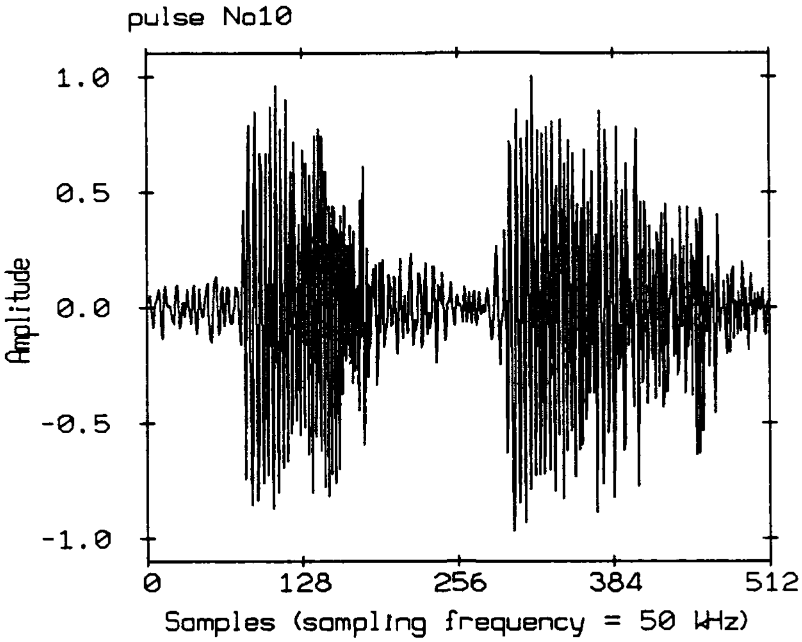


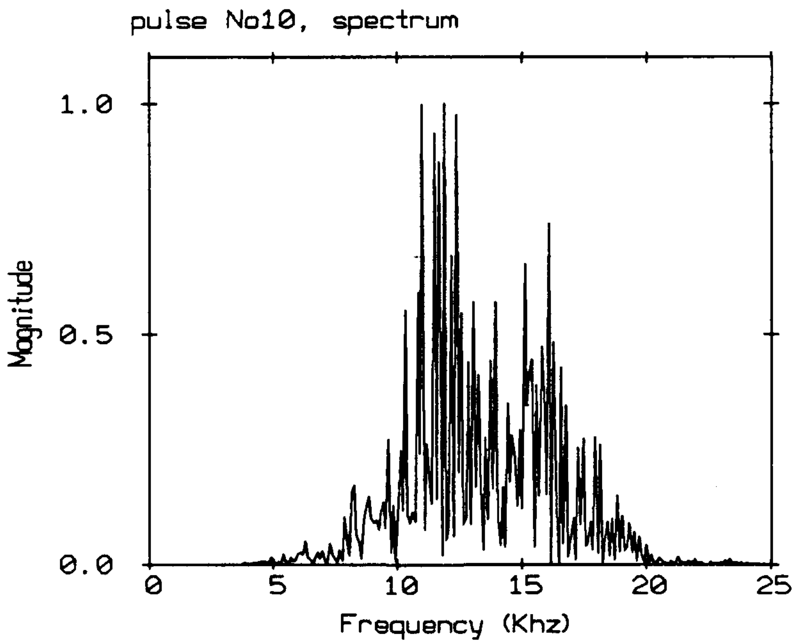
171607.1.ch4 , pulse No8



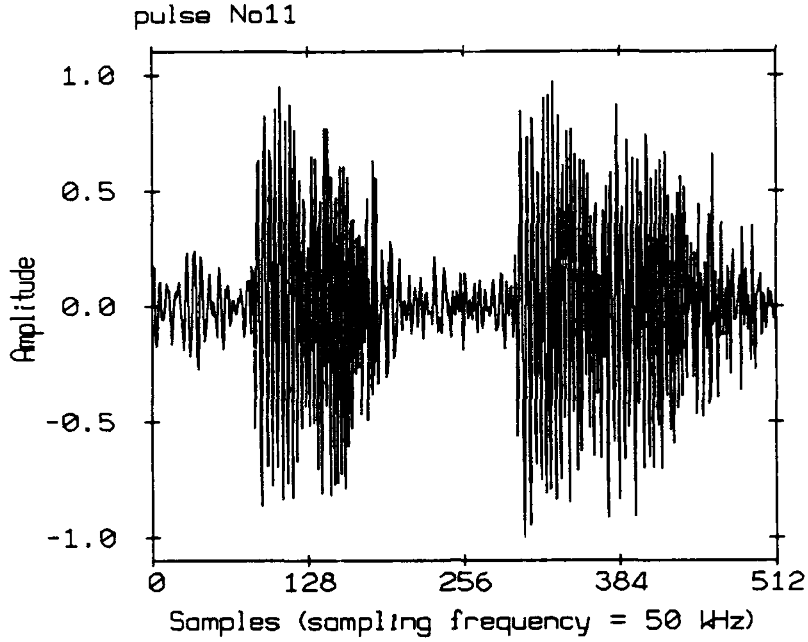


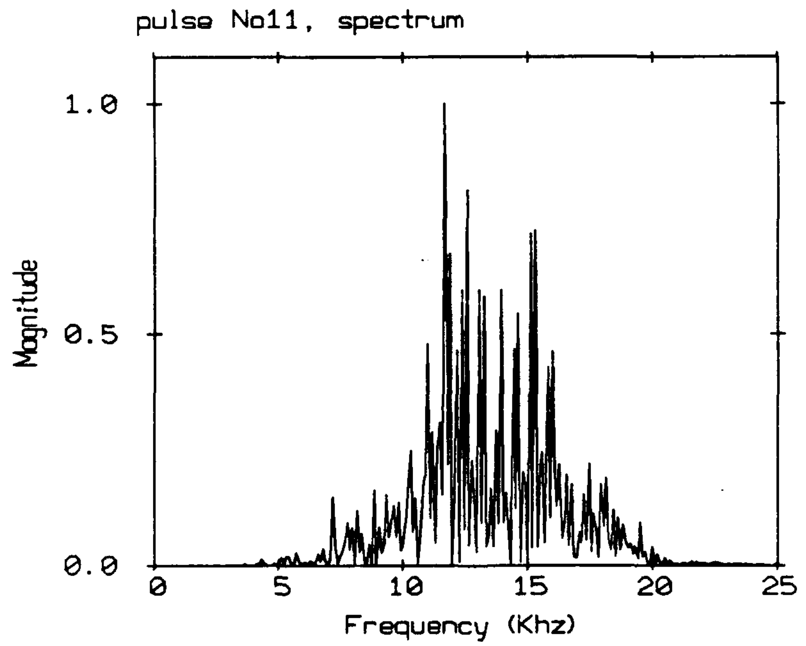
171607.1.ch4 , pulse No9



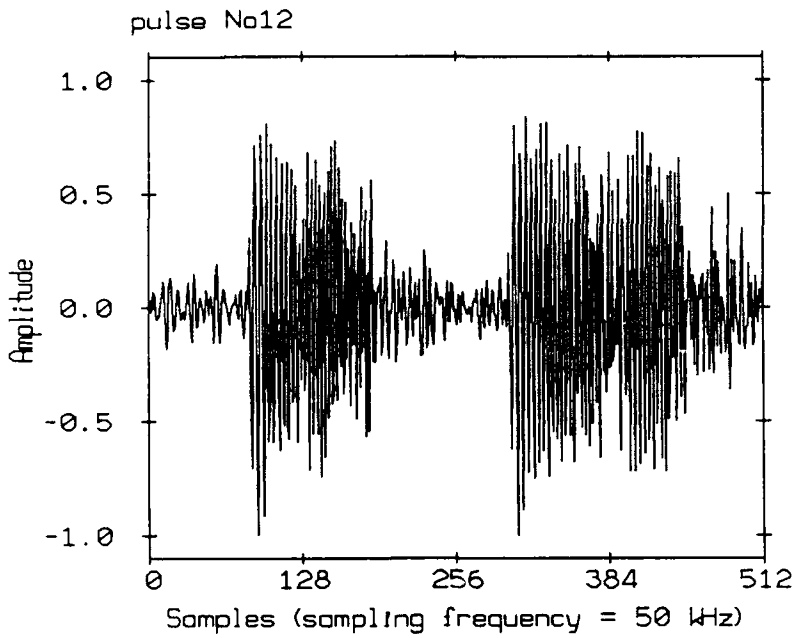


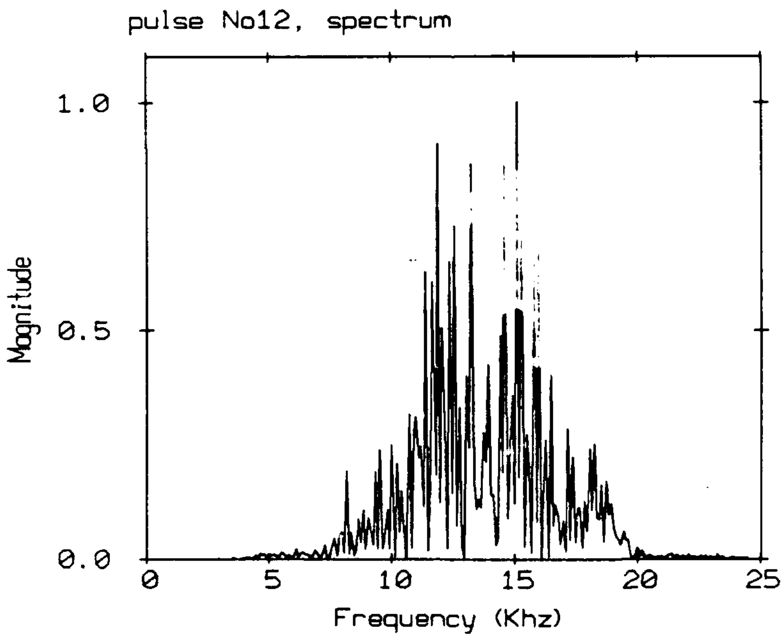
171607.1.ch4 , pulse No10





171607.1.ch4 , pulse No11





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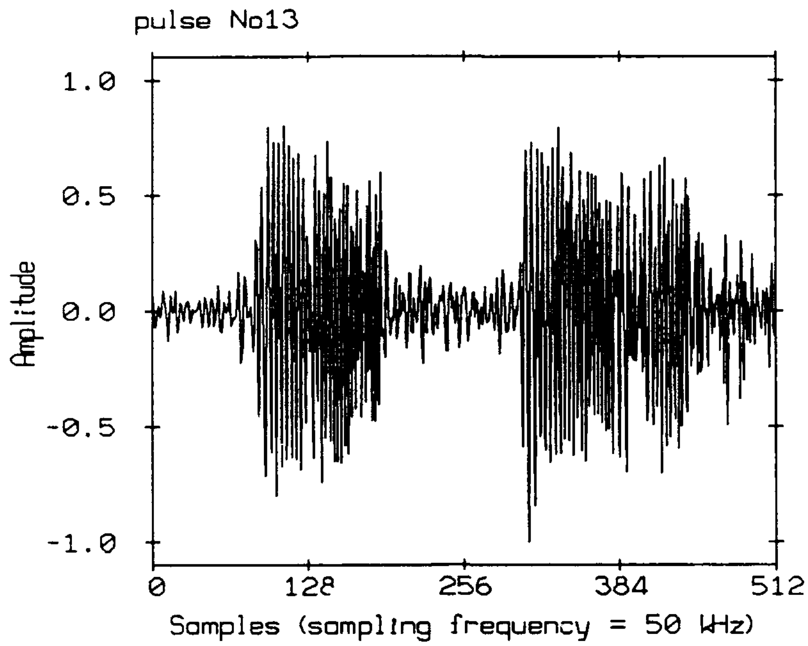

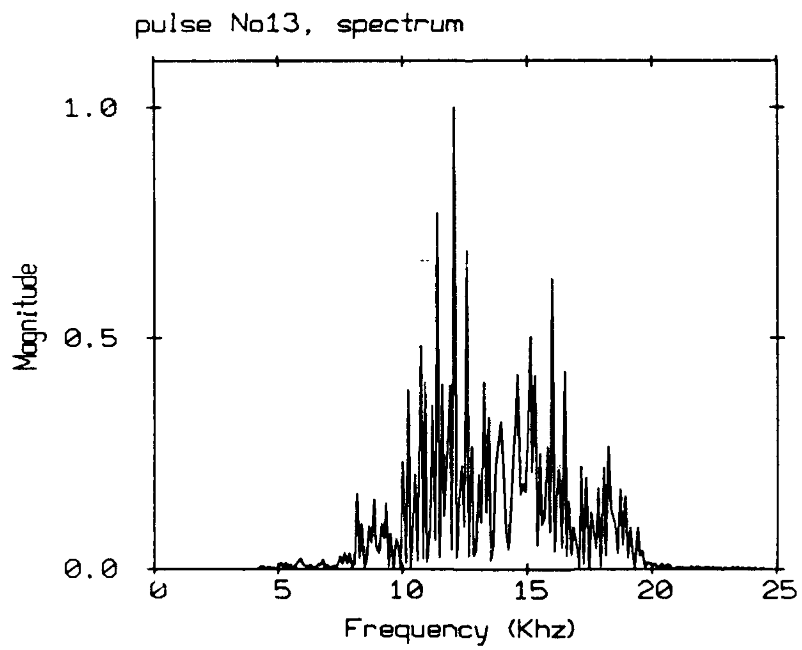

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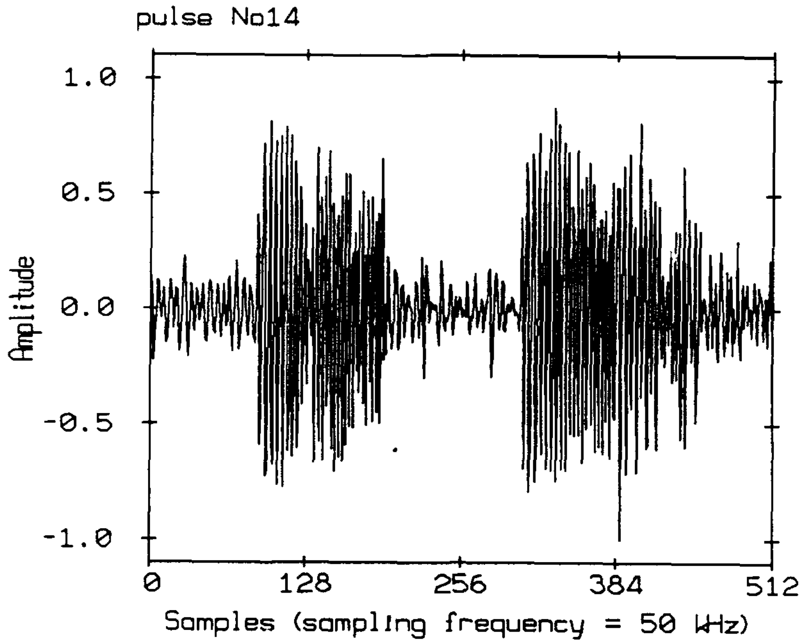

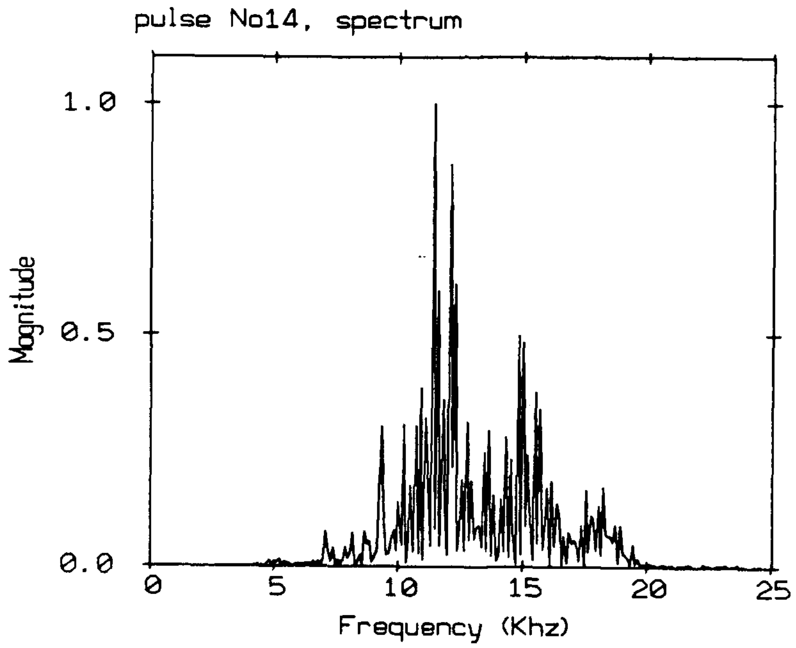

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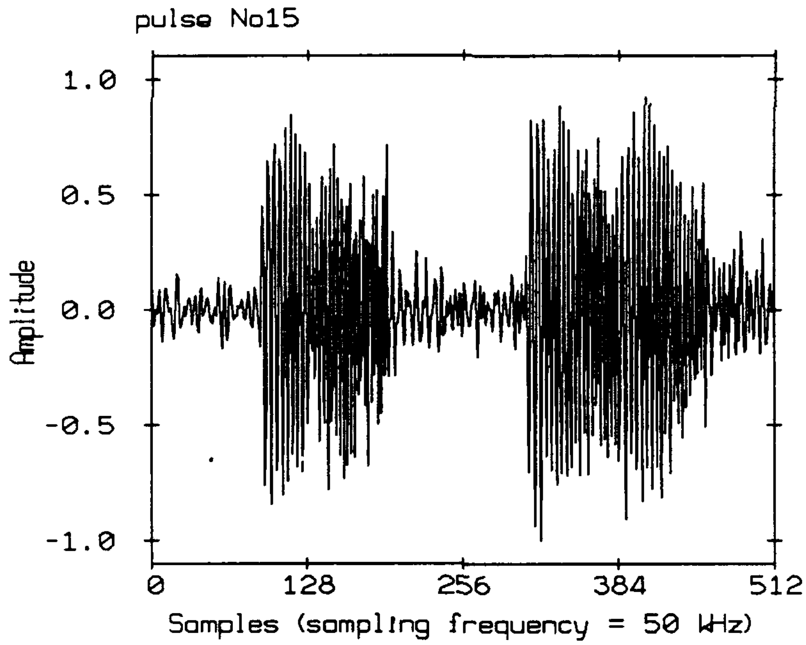

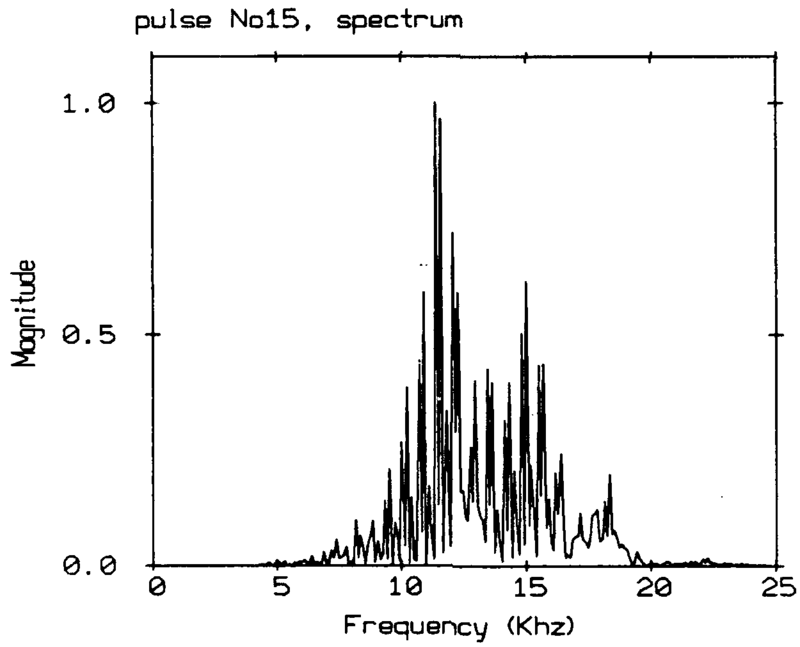

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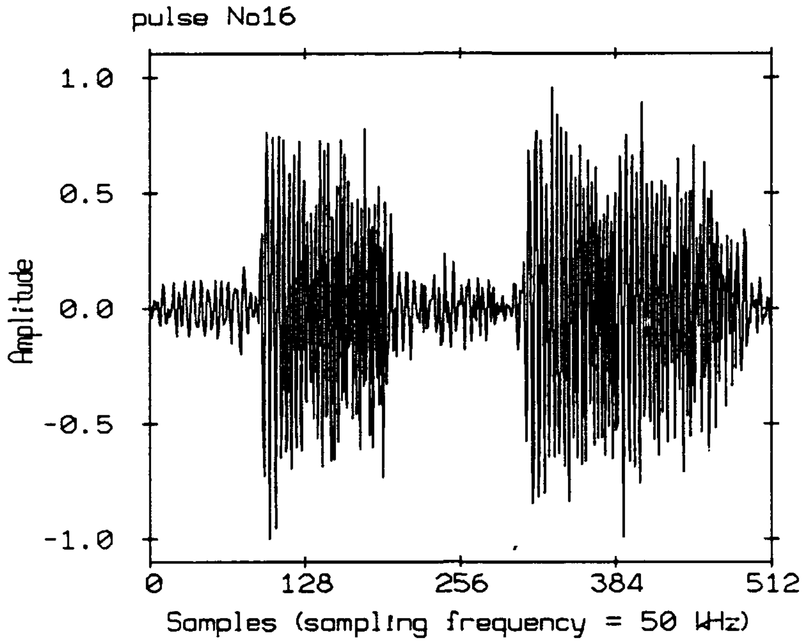

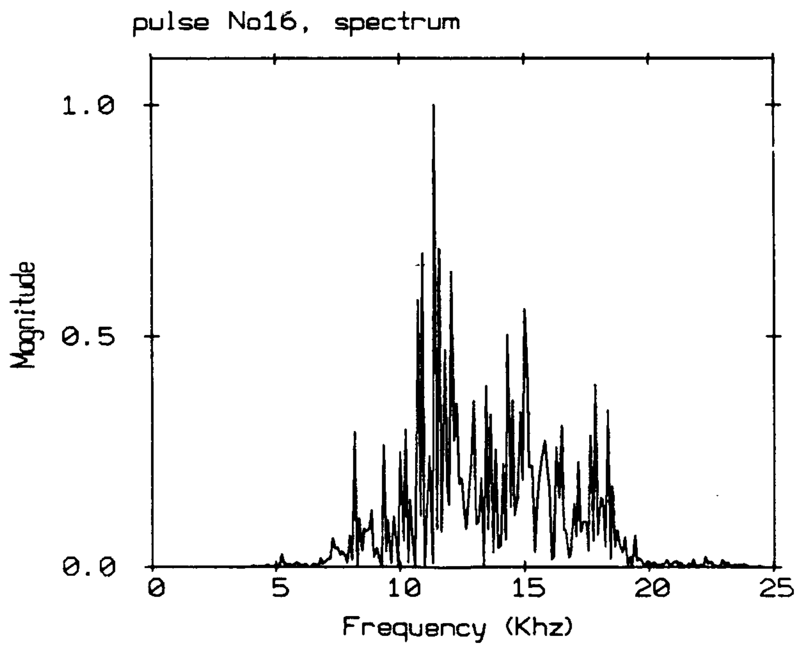

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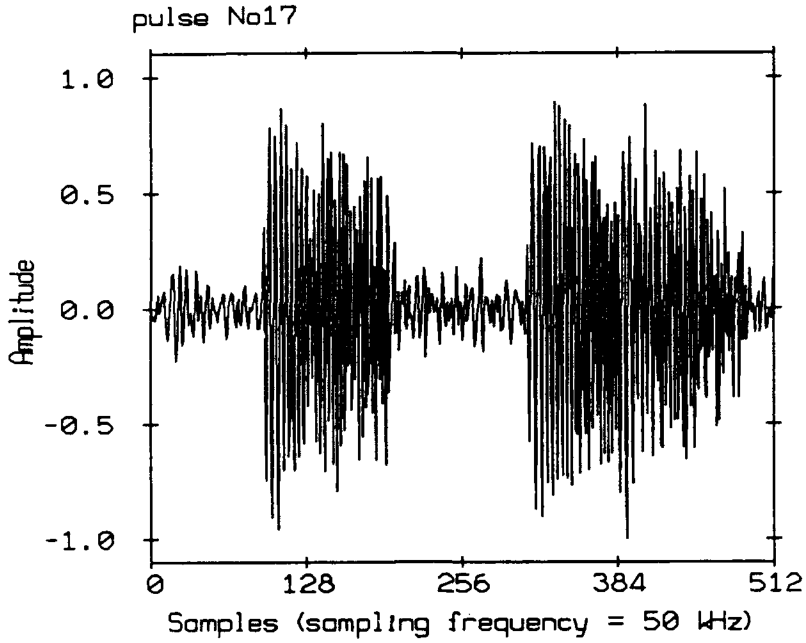

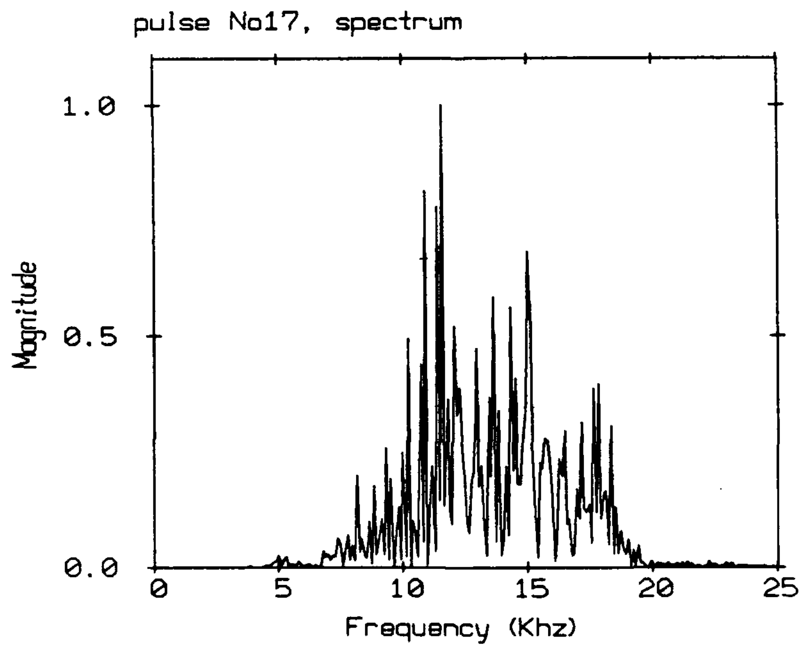

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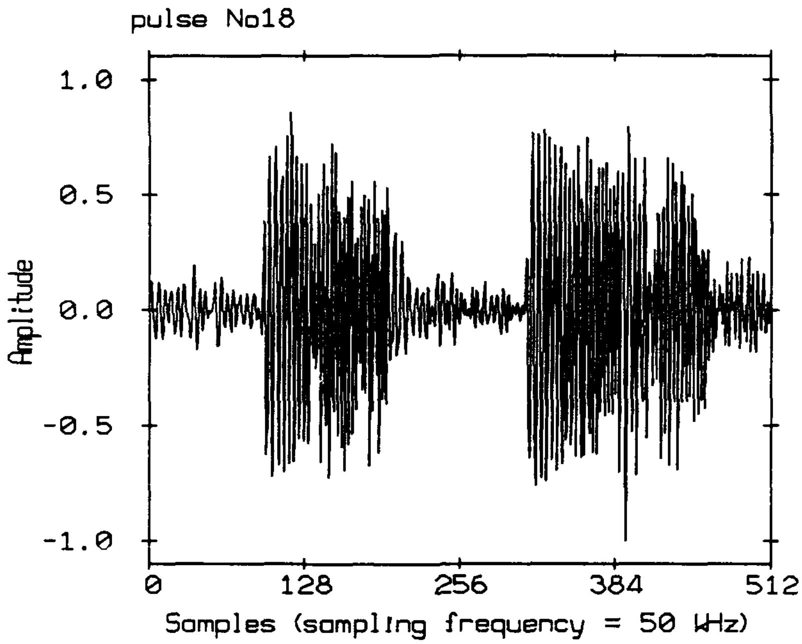

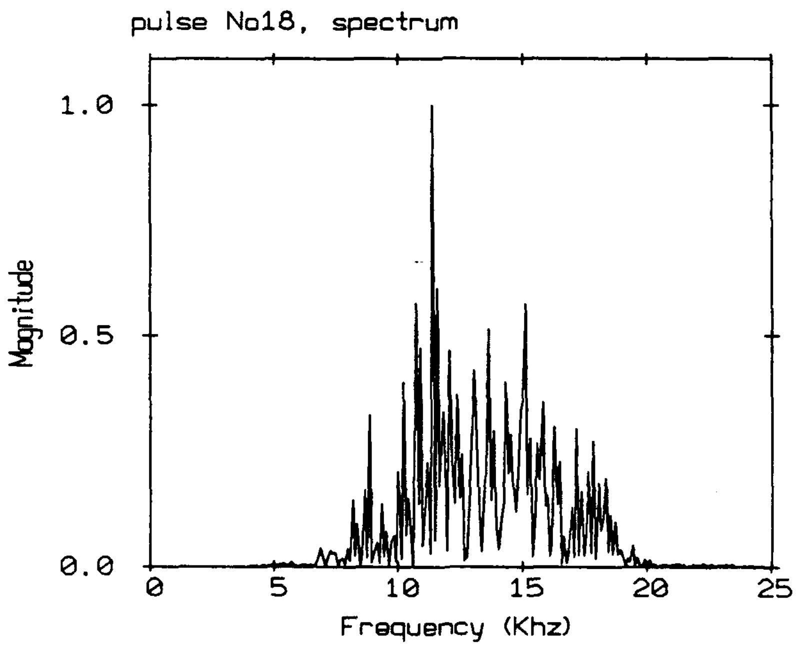

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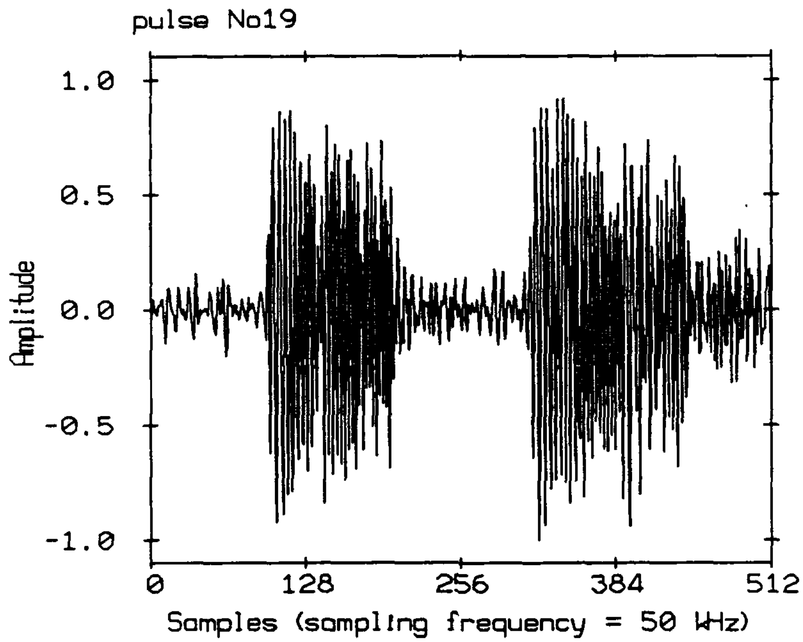

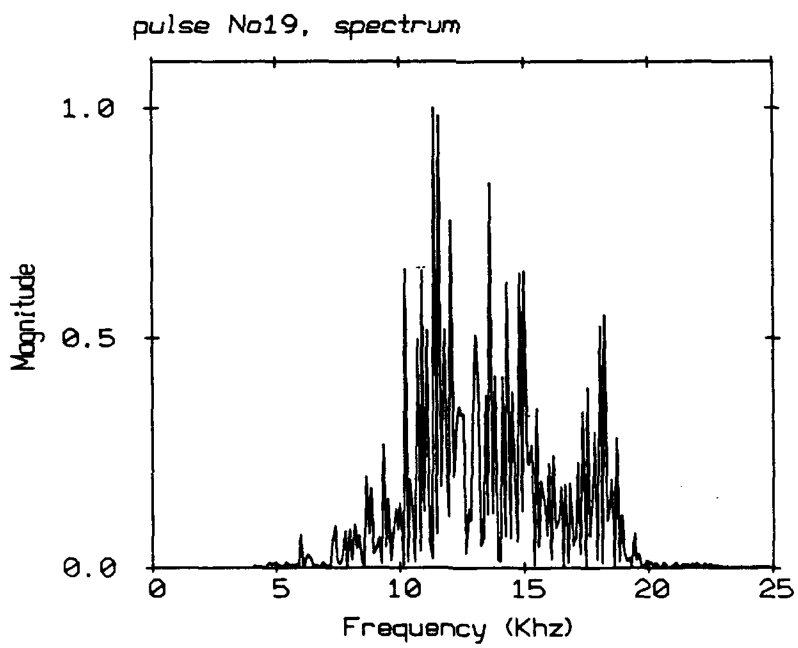

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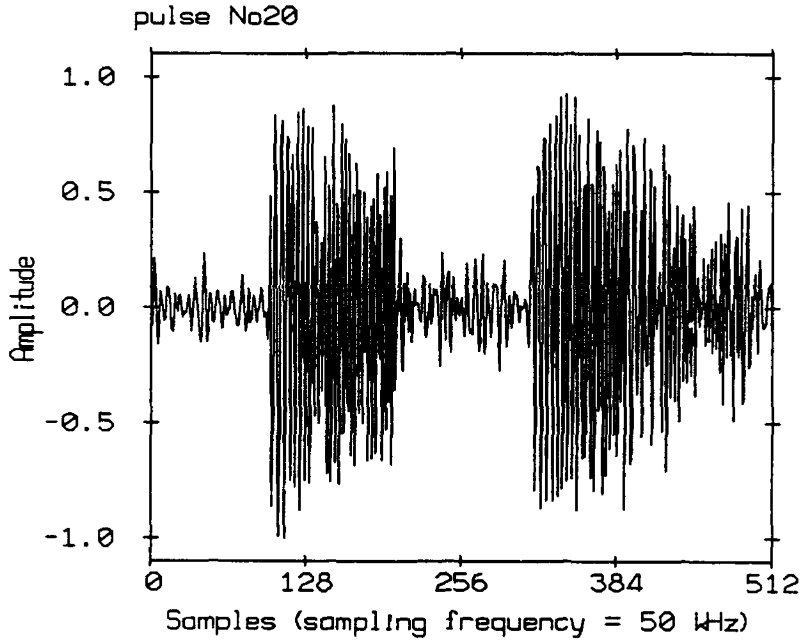

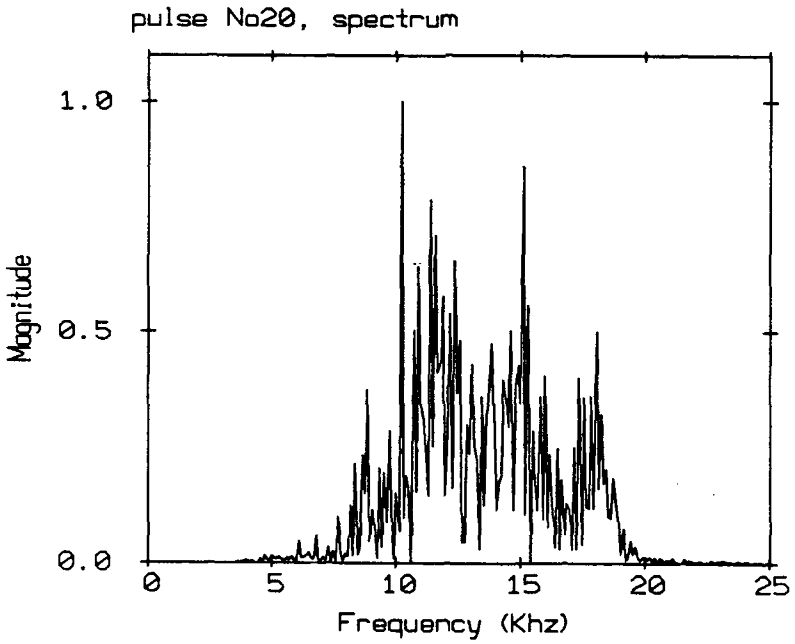

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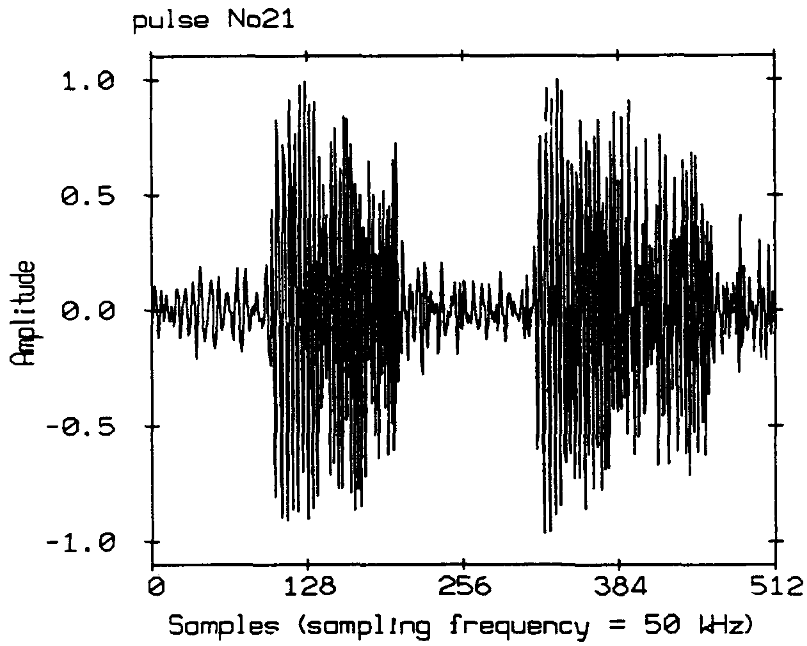

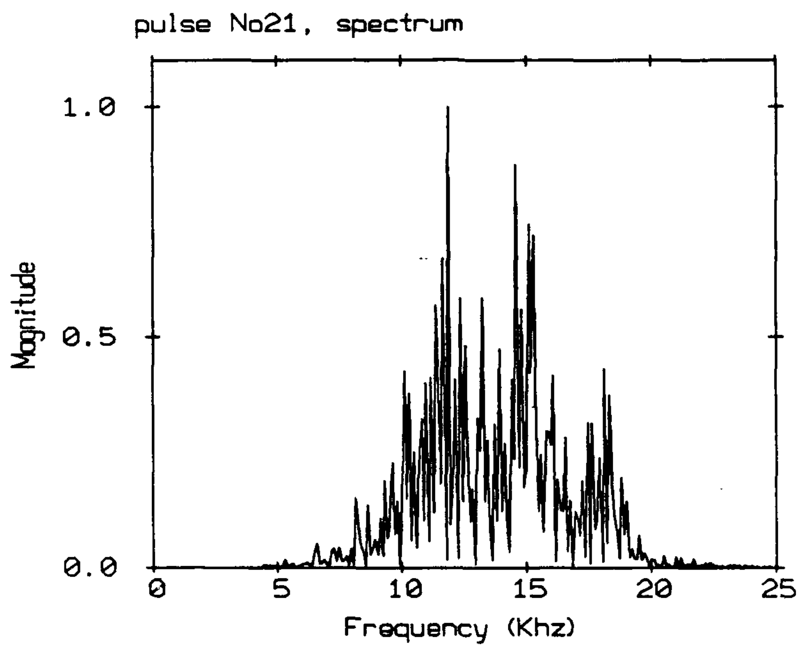

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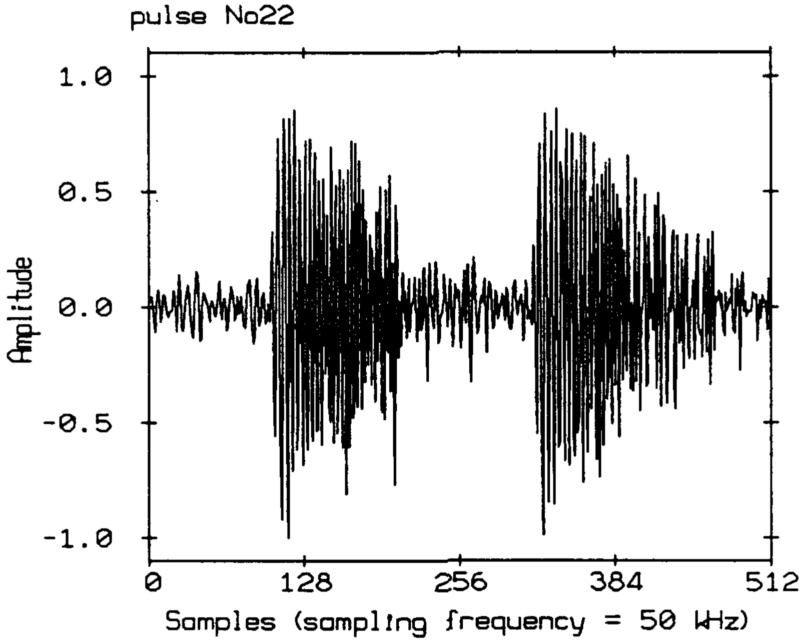

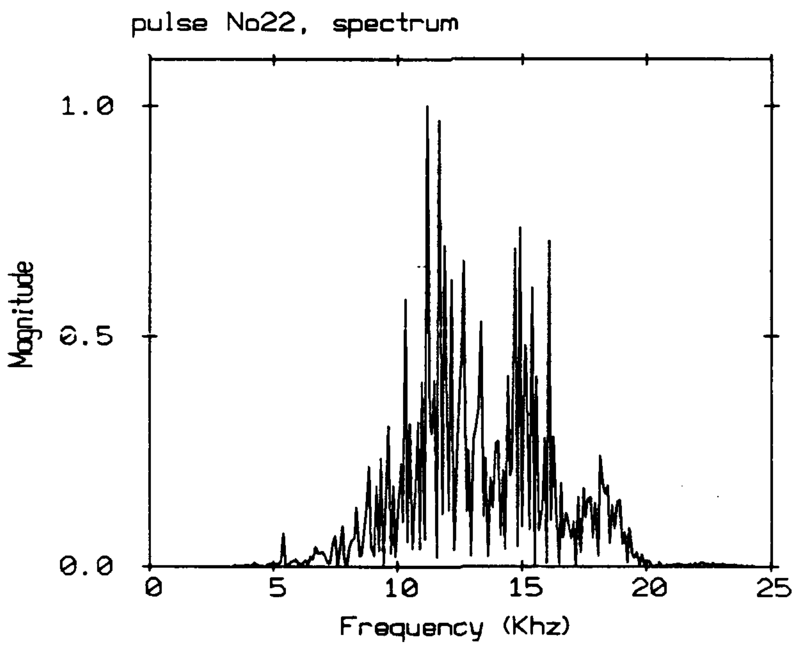

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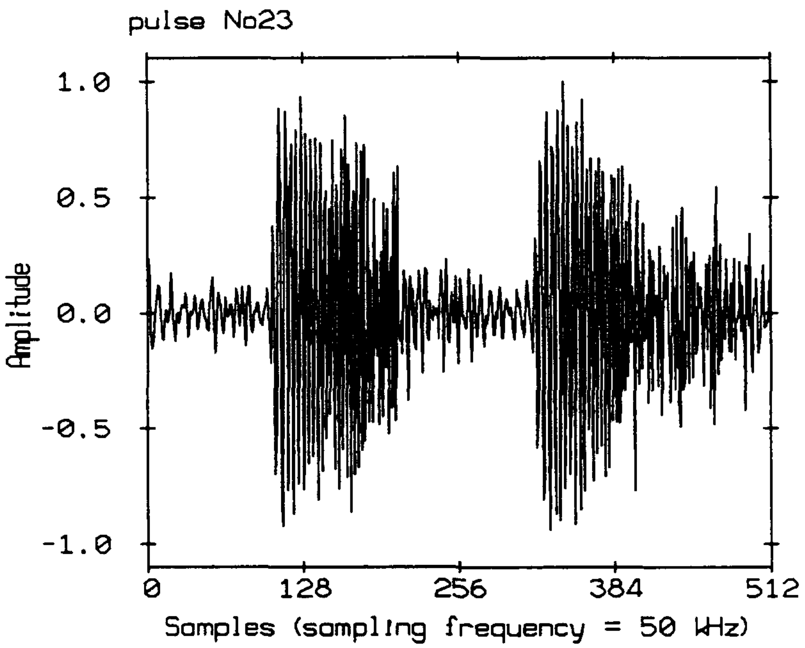

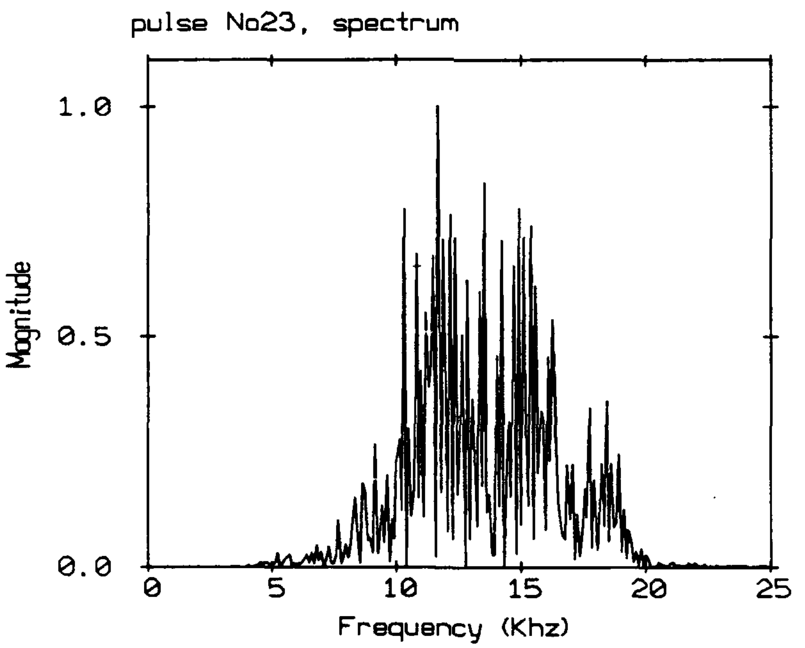

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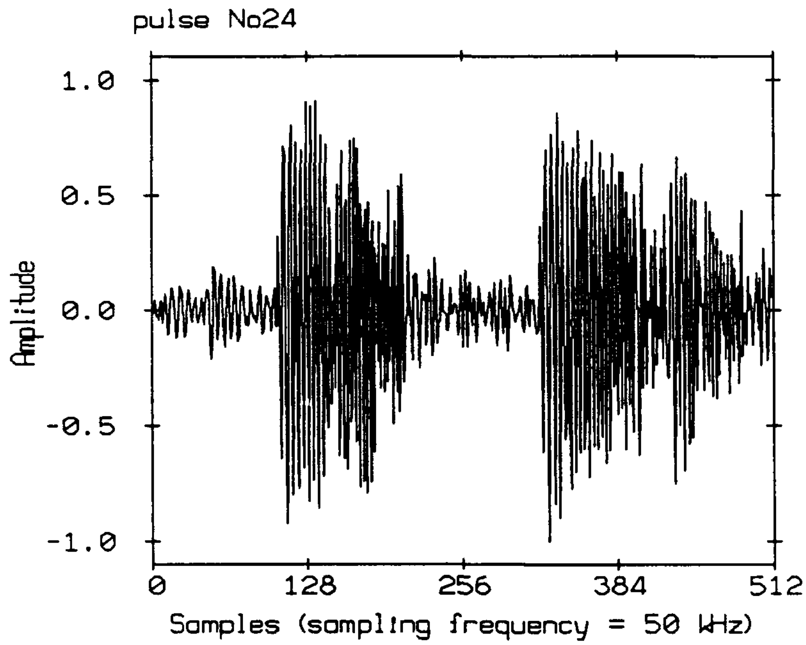

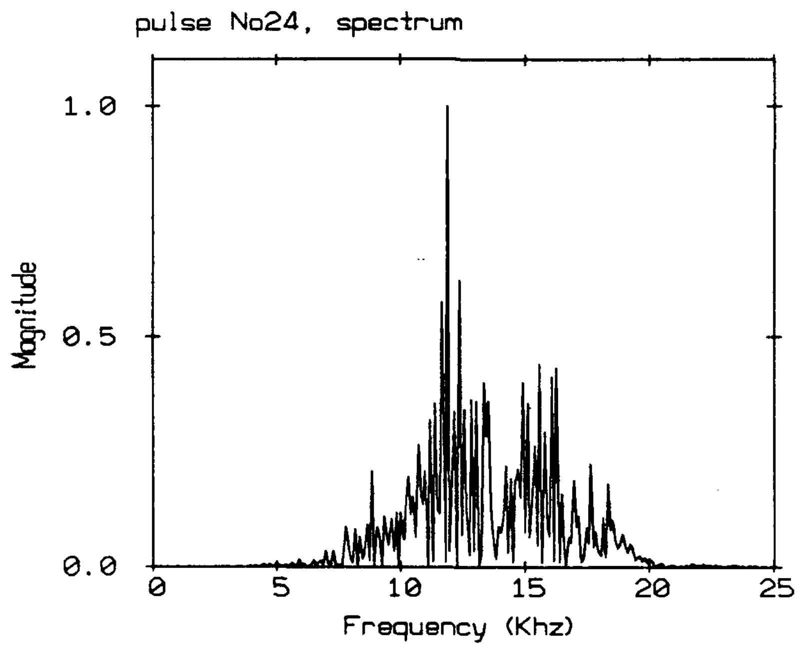

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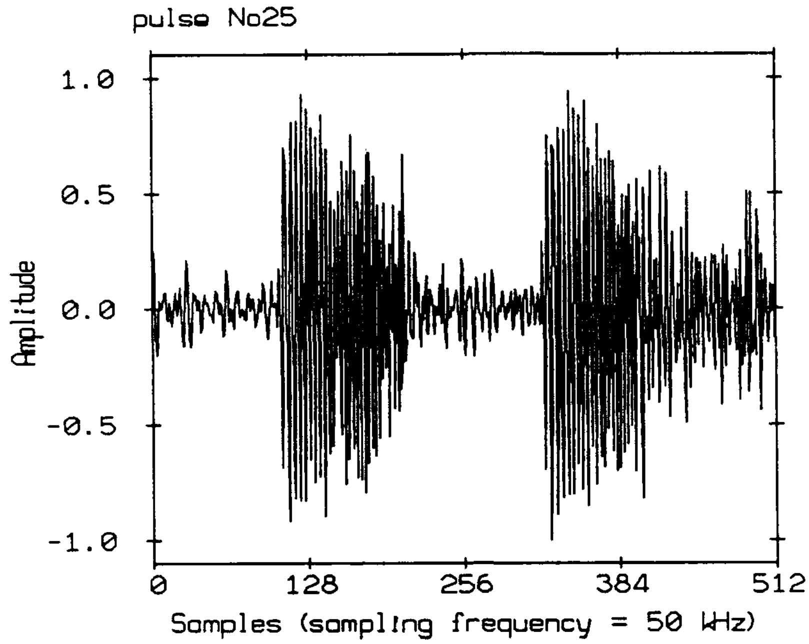

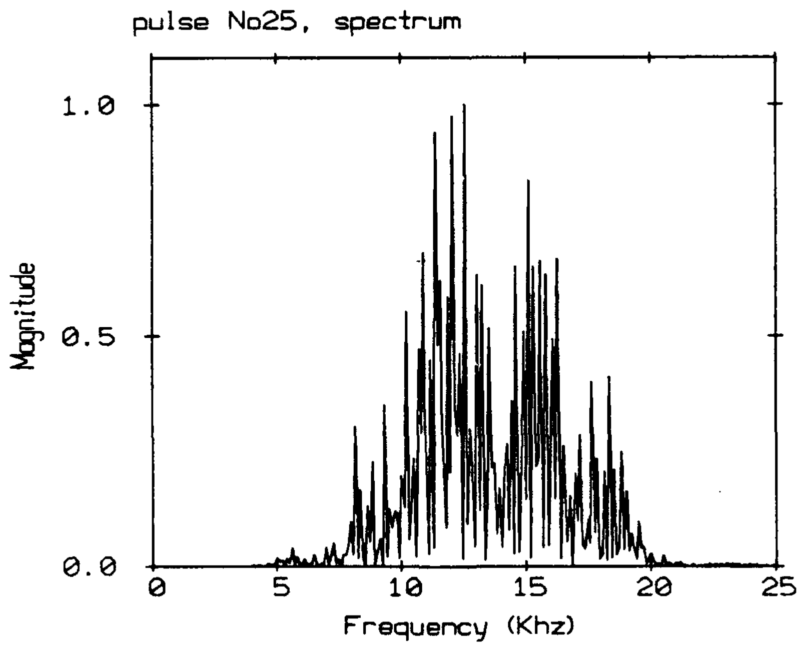

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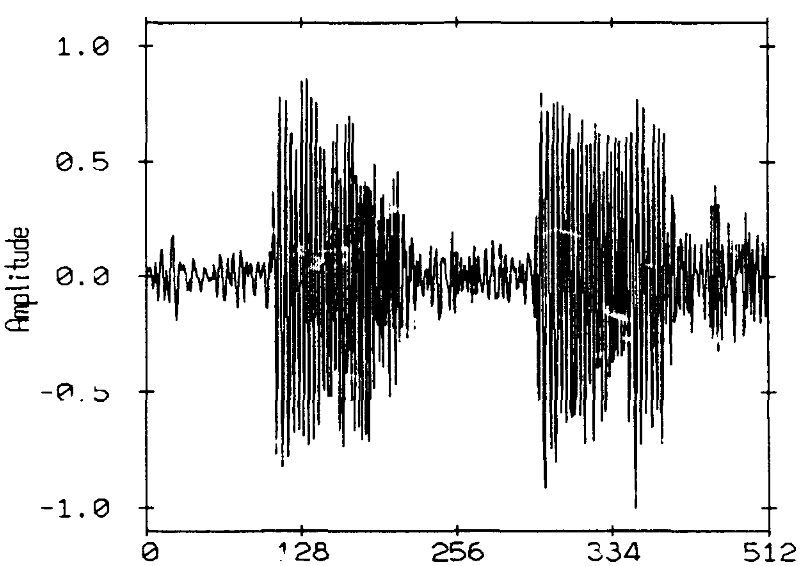
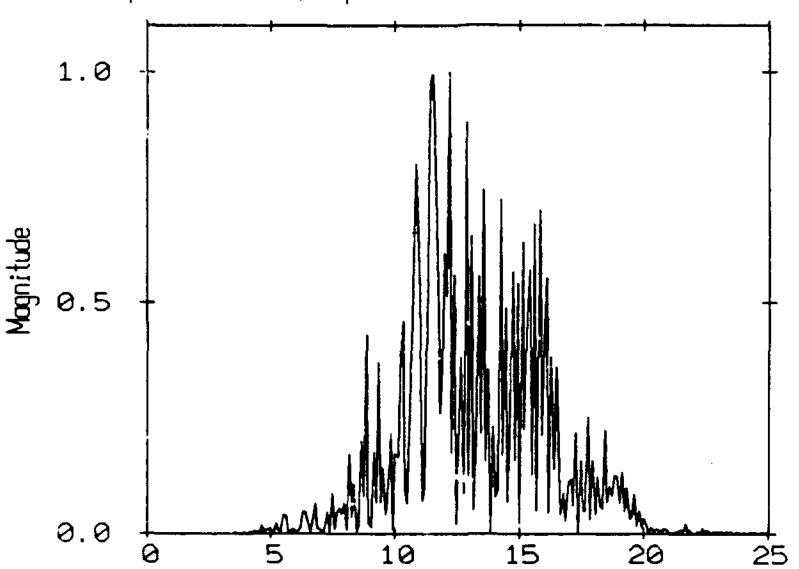
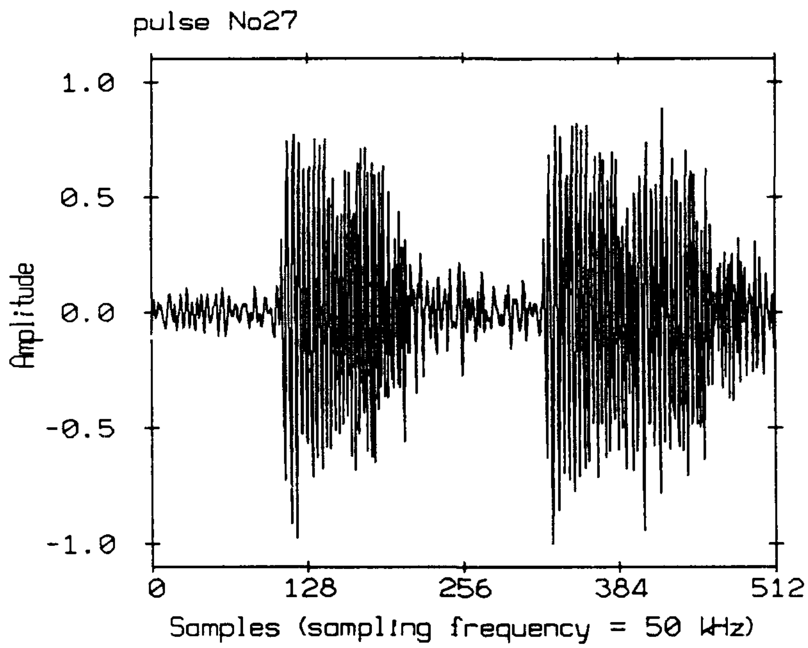
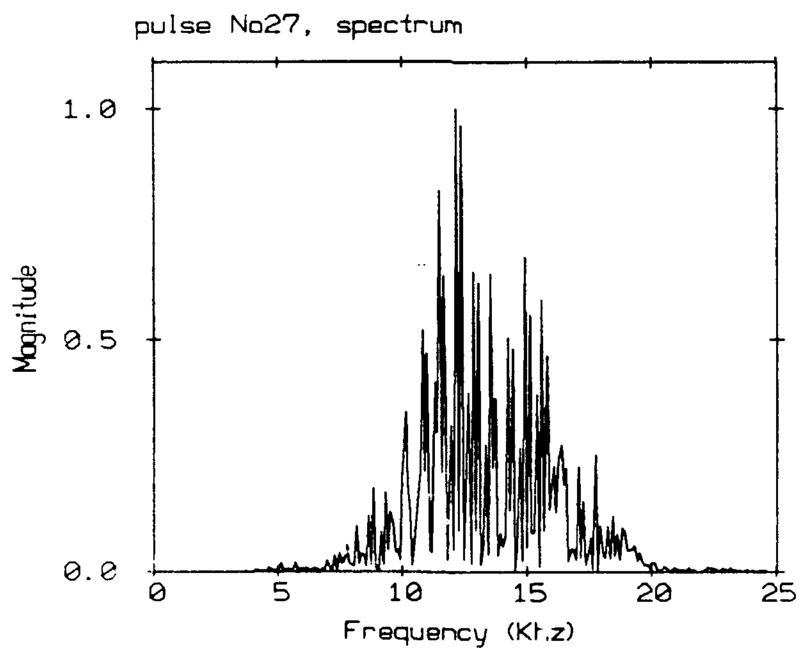


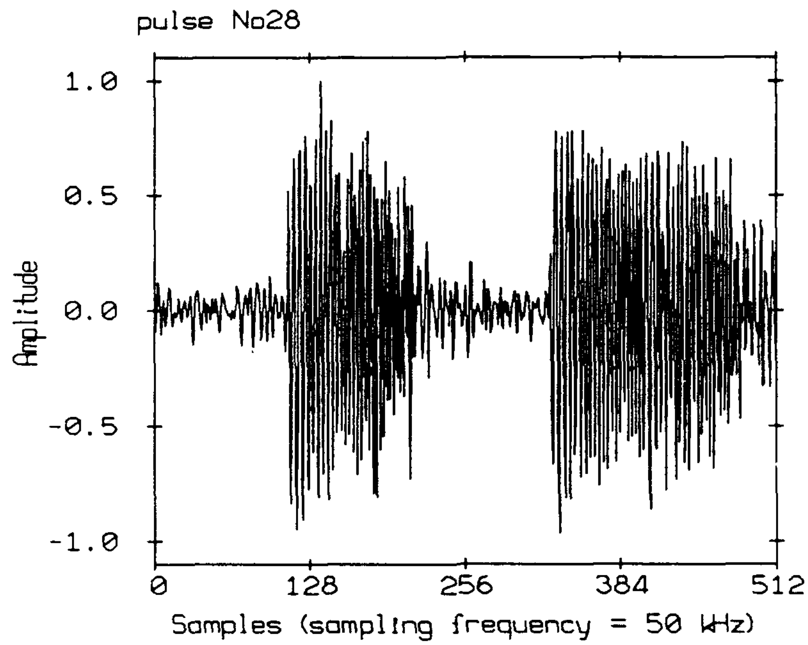


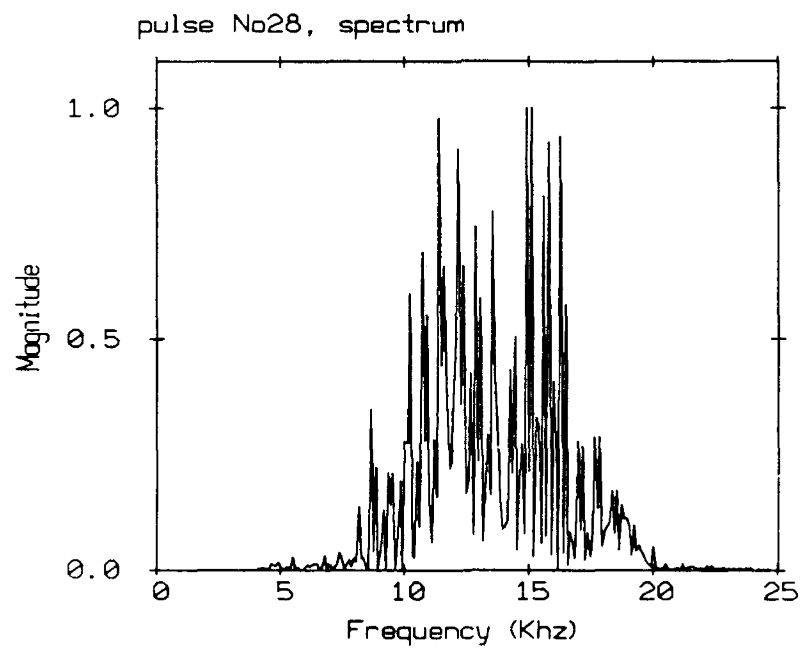
171607.1.ch4 , pulse No26





171607.1.ch4 , pulse No27





171607.1.ch4 , pulse No28

III.2 The channel multipath characteristics

The waveforms that are received by the sonobuoys are distorted replicas of the transmitted signal plus many other delayed replicas that result from the multipaths (see Figures 2.4 and 2.5). Figure 3.63 shows is a ray trace based on the sound speed profile, and the location of the receiver and the transmitter. This program calculates the ray traces, the time delay between the rays and the attenuation of each of the paths.

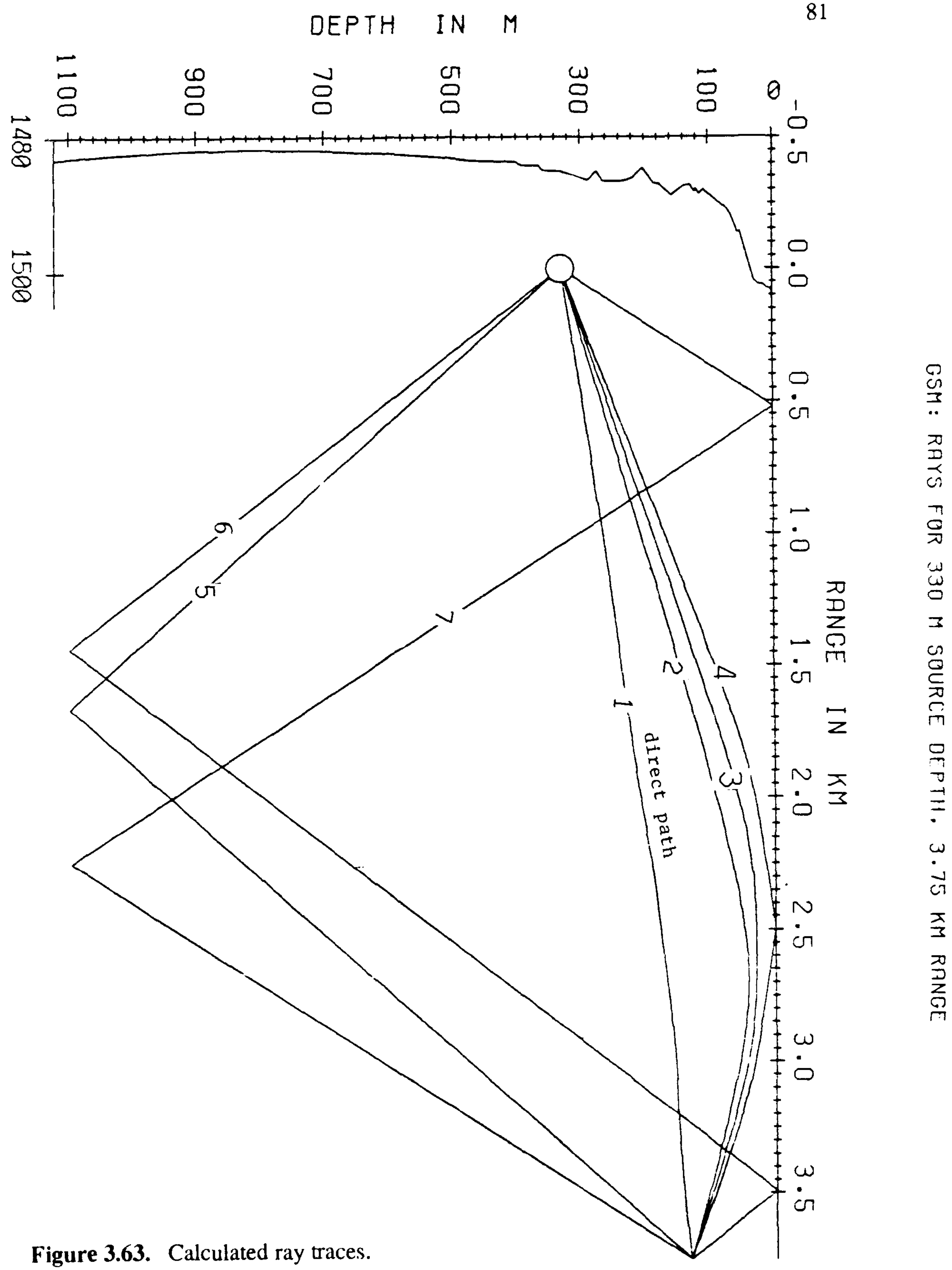


Figure 3.63. Calculated ray traces.

Table 3.1 gives the transmission loss (TL) and the time delay of each of the paths as calculated by the ray tracing program.

Ray No.	TD	TL
	Sec	dB
1	2.5261	-84.6
2	2.5321	-82.6
3	2.5322	-79.2
4	2.5334	-85.7
5	2.7856	-91
6	2.8638	-92
7	2.9974	-93

* TD = Time Delay

* TL = Transmission loss

Table 3.1. Ray delay and transmission loss.

The multipath characteristic of the channel are calculated in two different ways. The first is based on inverse Fourier-transforming the ratio of the received and the transmitted chirp waveform spectra. The second is by correlating the received and the transmitted waveforms and envelope-detecting the result. Figures 3.64-3.67 show the multipath character as calculated by using the correlation method.

The channel multipaths characteristics can be considered as two phenomena. The first consists of the major paths (macro-multipath) caused by reflections from ocean surface and bottom. The second consists of micro-multipaths. The micro-multipaths are due to microstructure in the ocean and are a collection of many closly spaced paths centered around each of the macro-multipaths.

Figure 3.64 shows the the direct path and the first multipath of 28 pulses as received by sonobuoy No 2. Figure 3.65 gives the second and Figure 3.66 the third multipath. Figure 3.67 gives the first three multipaths as were recorded from sonobuoy No 4.

Typically, the channel multipath characteristics are characterized by the received direct path being much weaker than the signal received from the first multipath (caused by reflection from the sea surface) (see Figure 3.64). The other multipaths having larger delay are caused by reflection from the sea bottom or from multiple reflections (bottom and surface) and are much weaker than the first multipath (Figure 3.65 and 3.66).

The underwater acoustic channel is a time-varying channel and hence, the channel multipath character also varies with time. This phenomena is well seen in Figures 3.64-3.67.

Careful inspection of the first 20 msec (Figure 3.64) shows not only that the multipath intensity changes with time but that the multipaths die and rebuild over a long observation time.

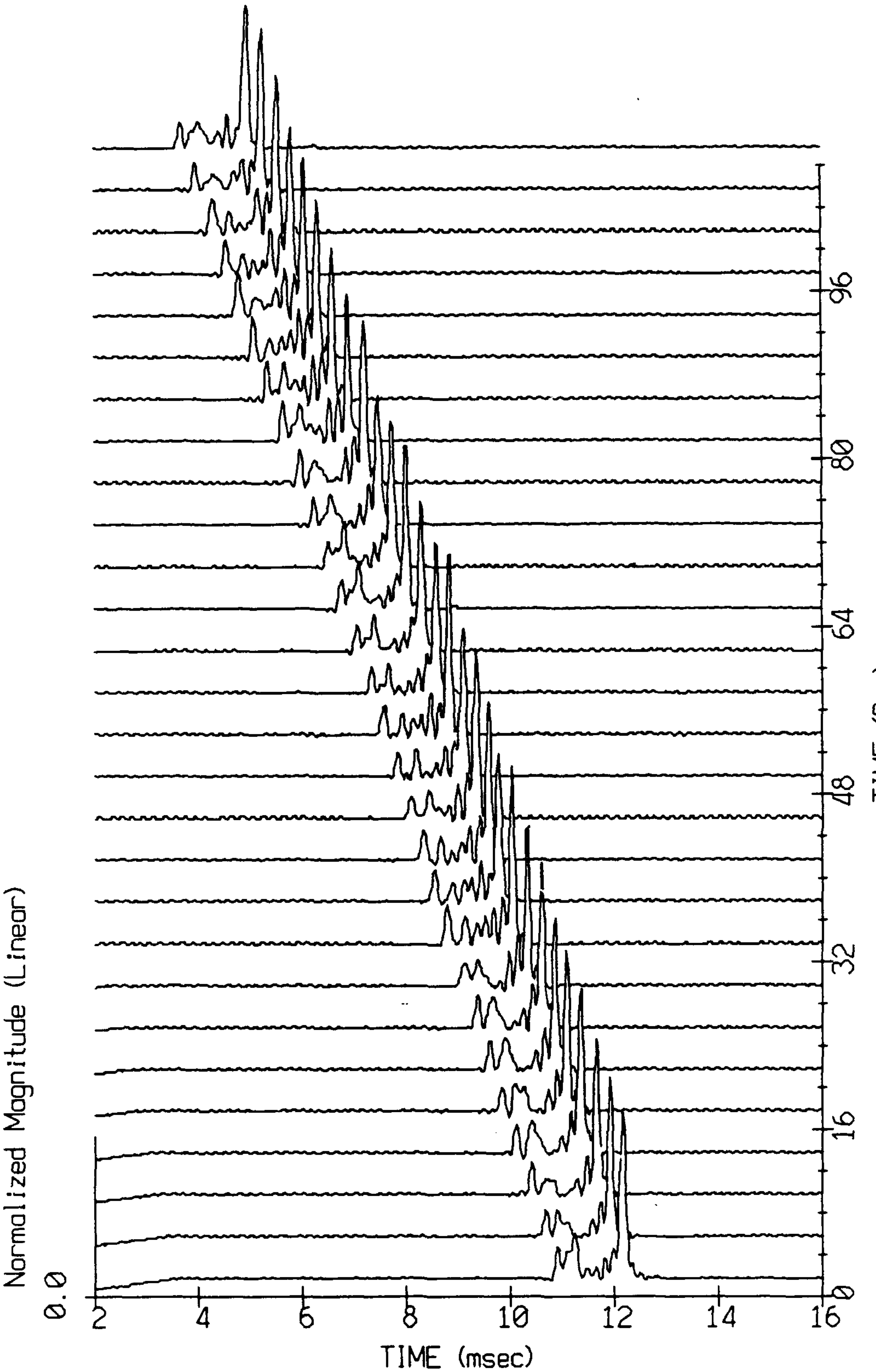


Figure 3.64. The channel character of the direct signal and the first multipath of the 28 2msec chirps as were received by sonobuoy No 2.

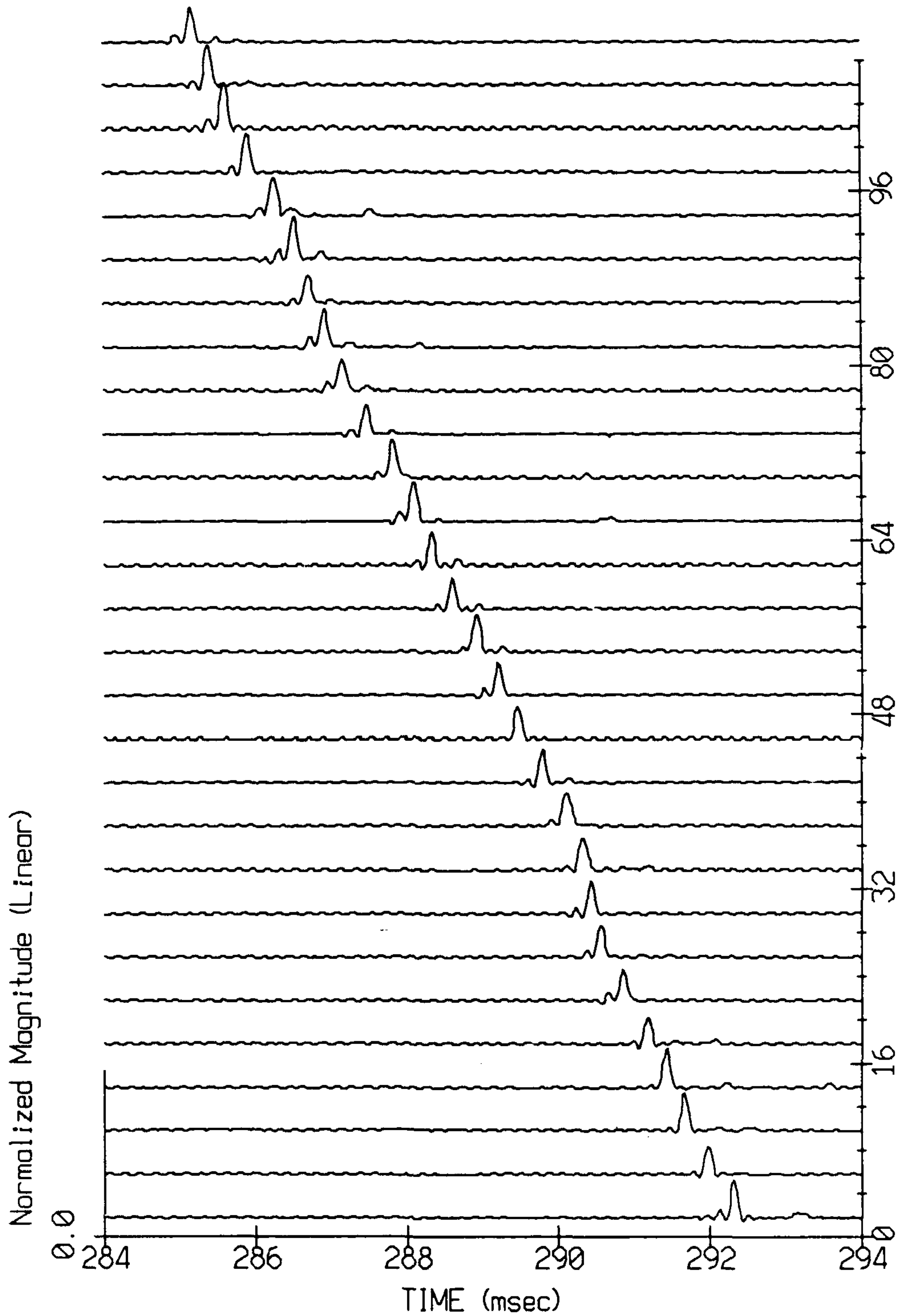


Figure 3.65. The channel character of the second multipath of the 28 2msec chirps as were received by sonobuoy No 2.

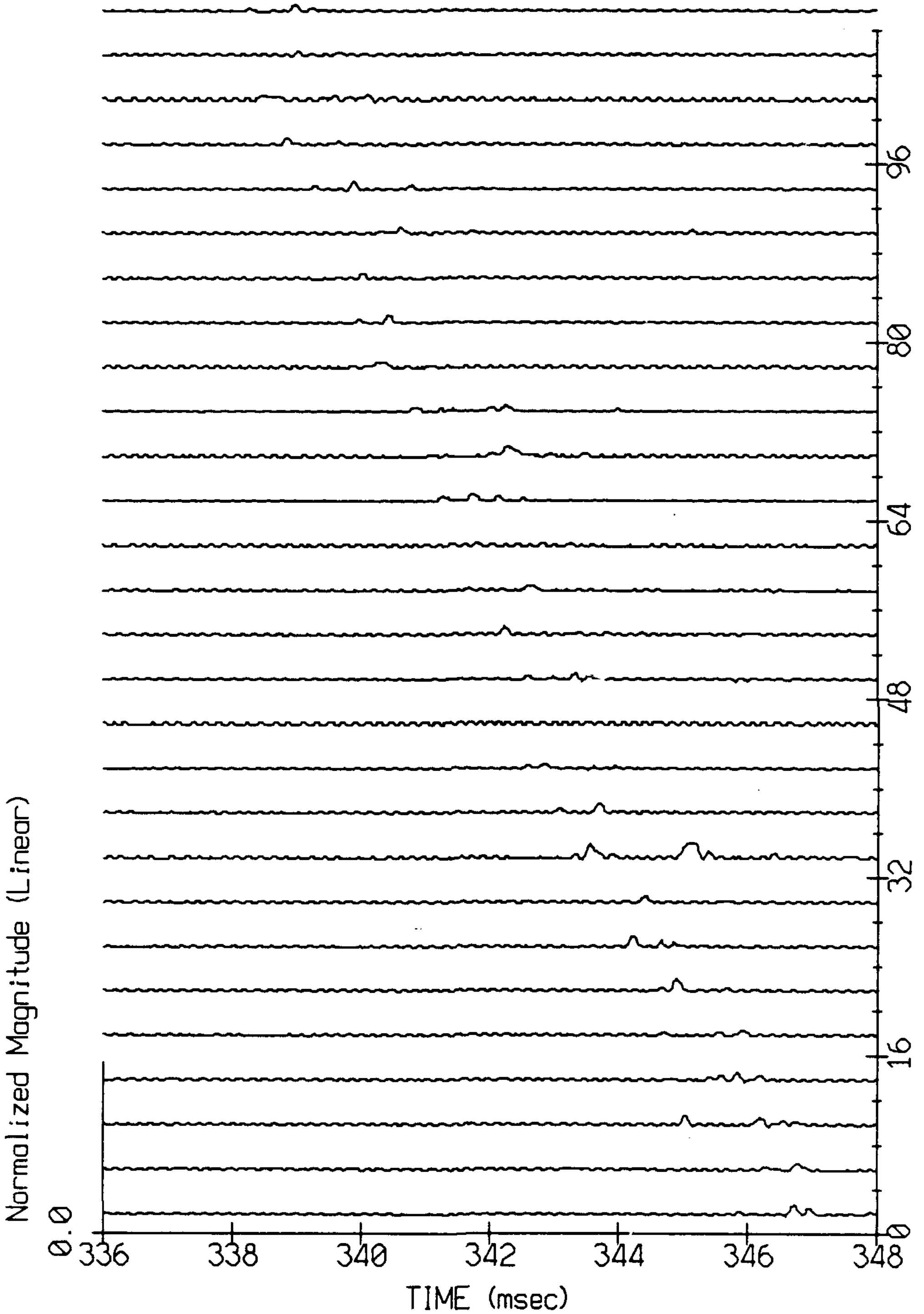


Figure 3.66. The channel character of the third multipath of the 28 2msec chirps as were received by sonobuoy No 2.

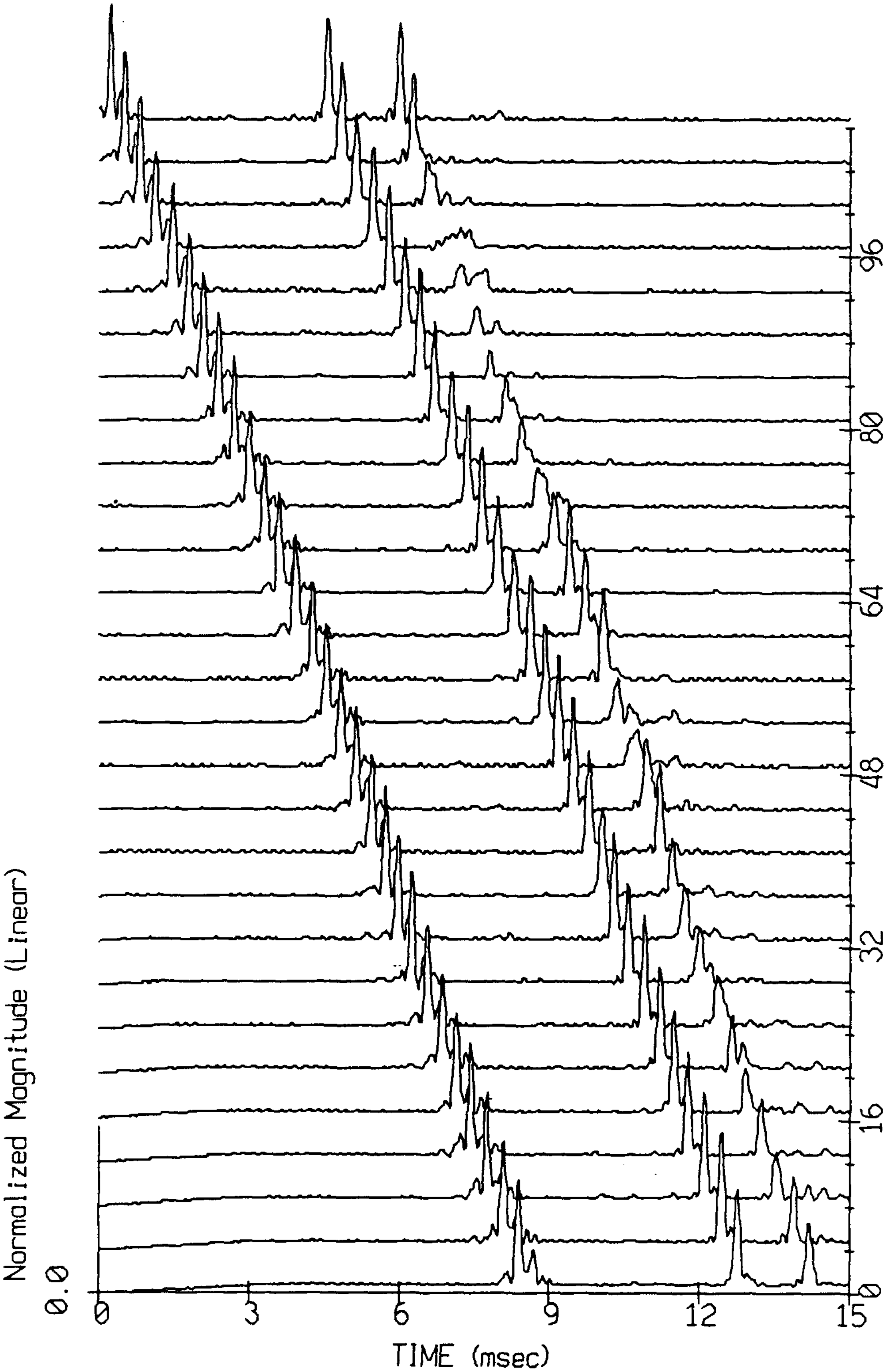


Figure 3.67. The channel character of the direct signal and the first two multipaths of the 28 2msec chirps as were received by sonobuoy No 4.

IV Discussion of results

The results of the first of a set of three experiments is analyzed here. In order to be able to characterize the nature of the ocean as an underwater communication channel, some carefully selected different waveforms were transmitted through the water. The received signals were analyzed to provide a preliminary idea of the nature of the channel. From the figures, we can clearly see that the ocean is a channel which suffers from very strong multipaths caused by reflection from the sea surface and the bottom. At times, one of the multipaths signals is stronger then the direct path (see Figure 3.64). Carefull inspection of the recieved signals (Figures 3.7-3.34 and Figures 3.35-3.62) shows that the channel is a time-varying channel. Moreover, comparing the received signals at different sonobuoys shows that the channel character is not only time-varying but also spatially dependent.

Acknowledgements

This work was supported by the Naval Research Laboratory under Contract N00014-88-K-2040.

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2. Mackenzie, K. V., "Nine term equation for sound speed in the oceans," *J. Acoust. Soc. Am.*, vol. 70(3), 1981.